DESIGN AND ANALYSIS OF HYBRID AC-DC MICRO GRID

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I hereby declare that the dissertation entitled "**DESIGN AND ANALYSIS OF HYBRID AC DC MICROGRID**" is being submitted on the partial fulfillment for the award of the degree of Master of Technology in "Power Electronics". The work has been carried out in the department of "Electrical & Electronics Engineering" (Oriental College of Technology, Bhopal) is an authentic record of my own work carried under the guidance of "Prof. Shravani mathur". I have not submitted the matter embodied in this report for award of any degree.

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ABSTRACT

Distributed generations (DG) which is renewable energy based has started dominating the industrial sector in recent years. Using wind, solar or biomass energy can be produce on small scale but it's not enough and efficient to be provided to the grid. Therefore, alternative techniques need to be found in order to harness these renewable energy sources as it will play a major role in world's energy production and tackle the problem of global warming. However, these renewable resources are weather dependent thus causing irregularity in the power supply and it is therefore difficult to figure out and monitor the consumption at any day. Because of all these reasons Distributed generators (DG's) are susceptible to discrepancies and system overloading.

In the course of time, DC micro grids are making its way into the power industry as the technology to harness DC power efficiently has improved. To use this DC power generated efficiently into AC system, integration of AC and DC system is carried out to form Hybrid AC/DC micro grid. Thus hybrid AC/DC micro grids offer the best solution to existing problems in power industry and thereby minimize the energy losses to a large extent. Along with these several problems are faced when these systems are practically implemented and those issues need to be addressed. This paper provides an overview on Hybrid AC/DC micro grid and highlights the issues in these system and the methods to overcome them by help of simulations.

The project proposes a hybrid system which combines AC and DC system interconnected with inverters so as to form a hybrid micro grid. On AC side, Photovoltaic (PV), Wind and Fuel cell are connected into the main grid. On DC side, two battery banks are used as a distributed generator. The impact of different wind speeds and sun irradiation have been investigated for this hybrid micro grid in both islanded and grid-connected modes of operation. A hybrid micro grid is developed and simulated using Matlab software. Steady state energy management performances as well as transient stability analysis have been analyzed for different case studies.

Keywords: Micro grids, AC micro grid, hybrid AC-DC micro grid, hierarchical structure, control strategy, energy management system, Windv System, Solar System.

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LIST OF SYMBOLS

Symbols used in this thesis are defined at appropriate places.

However, for easy reference, the symbols are listed below.

Rs	Series resistance
Rsh	Shunt resistance
VD	Diode voltage
Is	diode reverse saturation current
VT	thermal voltage
KB	Boltzmann constant
T	Temperature of PV cell
Irr	Solar irradiance
Isc	Short circuit current
Ki	Temperature factor of short circuit current
Io	reverse leakage current
Q	Electric charge
I	Output Current
Ns	Series PV cells
Np	Parallel PV cells
Voc	Open -circuit voltage
Irs	reverse saturation current
Eg	Energy band -gap
Tr	reference temperature

LIST OF ABBREVATIONS

Abbreviation used in this thesis is defined at appropriate places. However, for easy reference, alist of abbreviations is given below.

DG	Distributed Generation
DFIG	Doubly Fed Induction Generator
MPPT	Maximum Power Point Tracking
BBDC	Buck Boost Bidirectional Converter
FC	Fuel Cell
DC	Direct Current
AC	Alternating Current
PV	Photo Voltaic
WT	Wind Turbine
MG	Micro Grid
SG	Smart Grid
SOC	State of Charge

CHAPTER 1

INTRODUCTION

1.1 Introduction

Energy in general means capacity or ability to produce work. Energy is essential part of our life and it's impossible to survive without it. As time passed by and with technological advancement humans were able to use this energy in various forms. Considering the utilization of energy in daily life it was possible to categorize it as renewable and nonrenewable sources. This thesis sheds light upon combine use of renewable sources i.e. solar & wind energy, hoping to discover and determine the extent to which energy generated using this technology is capable of satisfying the demand of energy. Using the combination of PV and wind renewable system has the advantage of using it in regions having higher wind speeds and less sunny days and the other way round.

The statistical data in recent years show that 33% of world population is non-electrified and most of such region lies in developing countries. The way in which such region can be electrified is either by extending the existing grid or by development of new isolated power systems using alternative energy sources? [1]

The existing power system i.e. the one running on diesel or coal, is facing many energy crises as well as causing environmental pollution. Additionally, the transmission networks in remote areas suffer from huge transmission line losses and techniques such as centralized power flow and low voltage distribution causes inefficient use of the energy. Because of all these existing problems there is a recent trend of looking towards alternativesources of energy. Thus renewable sources are becoming more popular and the concept ofmicro grid came into existence so as to provide clean, reliable, efficient and flexible sourceof energy to the end user.

Supplying power to small electrical loads at remote locations or isolated grids Hybrid PV/Wind power generation systems have become a prevalent option as it offers highly reliable solution for continuous power supply. Most previous studies of these systems concentrated on local feasibility analysis. But the practical application of these systems

Ne ed is to consider parameters such as stability, control and reliability. Therefore, in this project characteristic of hybrid PV/Wind power systems is investigated by applying simulation modeling.

1.2 Background and Motivation

It is universally acknowledged that the control of power has been a crucial problem in micro grid. In micro grid, the control of active power, reactive power, voltage, frequency are all challenges. Even a small mistake in control of power could cause severe damage to the whole power system; for instance, the Northeast Blackout which had caused millions of people away from the electricity throughout parts of the Northeastern and Midwestern United States and the Canadian province of Ontario, happened because of the control problem of the alarm system. A lack of alarm left operators unaware of the need to re- distribute power after overloaded transmission lines hit unproved foliage, which triggered arace condition in the control software [2].

Another instance is the 2012 India Blackout, in which two severe power blackouts caused a shortage of 32 GW and affected over 300 million people on 30 and 31 July 2012 [3].

The problem of power outages has made many disasters and tragedies in human history and most of them happened due to the poor control of the power grid. Therefore, it is crucial to make sure that power is running under good control.

Furthermore, the environment has been affected by the traditional power generation methods. However, micro grid is capable of integrating renewable resources such as wind and solar, which has much less pollution than that of the traditional power sources. As an environmentalist who is interested in power and energy, determined to focusing on the design and control of the micro grid.

Hybrid AC-DC technology consists of mostly the renewable sources. These sources are available in abundant and can be utilized to maximum extent possible. These technologies previously consisted of only Batteries, wind turbines and diesel to supply the load, but was

not sufficient to manage the load as the system was not stable in different conditions. Thus to overcome this problem, controller is used along with addition of PV module. Output of the PV arrays depends on the irradiation of the sun and it varies depending on the location. It's necessary to carry out the transient analysis in such conditions were number of number of Distributed Energy Resources (DER's) are present. Transient analysis will help in verifying the stability of this system during the occurrence of fault on different locations. This can be done by using Matlab simulation.

1.3 Micro Grid

There are a number of definitions for micro grid. The U.S. Department of Energy defines micro grid as "a bunch of interconnected loads and distributed energy resources with boundaries that performs as an entity with control capability". The Working Group, Micro grid Evolution Roadmap describes it as an "electricity distribution system that consists of distributed generators and loads that can be operated coordinately either while connected to the power grid or while isolated" [4]. From the definition of EU research projects, micro grid is composed of low-voltage distribution systems with distributed energy resources (PV, wind turbine and fuel cell) and storage devices such as energy storage system and flywheels [5]. The primary purpose is to ensure local, reliable, and affordable energy security for urban and rural communities. It also provides solutions for commercial, industrial, and federal government consumers [6]. Furthermore, micro grid can be connected and disconnected from the grid to enable it to operate in either grid- connected or islanded mode. An ideal micro grid should also perform the following benefits as shown below [7]:

- "Ensures power quality, reliability, and security for end users and operators of the grid"
- "Elevates the integration level of distributed and

renewable energy resources"

- "Cost competitive and efficient"
- "Enables smart grid technology integration"
- "Minimize carbon footprint and greenhouse gas emissions by maximizing clean local energy generation"

Micro-sources having low cost and voltage, high reliability are laid out at customer site. These micro-sources are power electronic devices and controllers that insure continuity of supply to the customer and reciprocate with the utilities. Micro grids (MG) have some defined characteristics as follows:

Decentralized

- Remotely dispatched
- Less than 50-100 MW
- Connected with distribution system

Micro grids are possibly implemented in two ways; it can be similar to small electrical generator to provide backup power or a complex system integrated with the Grid consisting of generation, storage and power management systems. These systems consist of a bunch of technologies on the supply side as well as on demand side and located at or near the location of loads. Thus MG technology has wide application for local controlling electricity usage.

1.4 Reasons for using Micro grid:

There are number of advantages for the conventional arrangement of modern large power system. Large generating stations are efficiently operated as they are interconnected by high voltage transmission network which operate efficiently to transfer bulk power at large distances with limited losses. In many cases the distribution network is designed for unidirectional flow and can shelter only customer loads. However, in recent years a lot of research is been done to improve the MG technology and the reasons encouraging them are [8]:

1. Reduction in gaseous emissions

2. Energy efficient

3. Deregulation or competition policy

4. Diversification of energy sources

5. Climate change problems

6. National power requirement

Investigation on the feasibility and benefits of MG is carried out by several research groups around the world as problems like dealing with unbalanced loads and harmonics associated with it needs to be rectified. However, this report does not concentrate on addressing such problems; rather it focuses on modeling the MG's to investigate the transient and steady state response.

As electric distribution technology improves over period of time, noticeable changes are seen that will alter the energy requirements. The required modifications are carried on demand side where high availability and efficiency is needed as well as in the supply side where the distribution network and other critical technologies merge to maintain continuity of supply.

Considerable changes are seen in power systems operations mainly because of deregulation and due to distributed energy resources (DER). DER has advantage that it allows micro source generations to participate and also utilize renewable energy sources (RES) like wind, solar or hydro technologies. Moreover, keeping them close to the load helps in reducing transmission line losses and avoids network congestions. Also power can be supplied without any interruption to the users and in case of any severe system collapse these micro-sources can be operated in islanding mode.

Using combination of gas turbines, fuel cells photovoltaic systems, wind turbines etc. micro grid supply electricity to the customers. The storage device in micro grid usually includes batteries and flywheels and this combination is similar to rotating reserve of largegenerators in conventional grid. It ensures balance between generation and consumption during rapid changes in load or generation side.

Technical studies need to be carried out in two major fields when distributed generators are installed. Firstly, without making large modifications in existing system the influence of distributed generators has to be deal with. Secondly, new concepts for utilization of micro grid have to be generated.

Hybrid AC-DC technology consists of mostly the renewable sources. These sources are available in abundant and can be utilized to maximum extent possible. These technologies previously consisted of only Batteries, wind turbines and diesel to supplythe load, but was not sufficient to manage the load as the system was not stable in different conditions. Thus to overcome this problem, controller is used along with addition of PV module. Output of the PV arrays depends on the irradiation of the sun and it varies depending on the location. Thus, in this project irradiance for Northridge and Texas is considered to see the effects on the power flow of system. It's necessary to carry out the transient analysis in such conditions were number of number of Distributed Energy Resources (DER's) are present. Transient analysis will help in verifying the stability of this system during the occurrence of fault on different locations. This can be done by using MATLAB simulation.

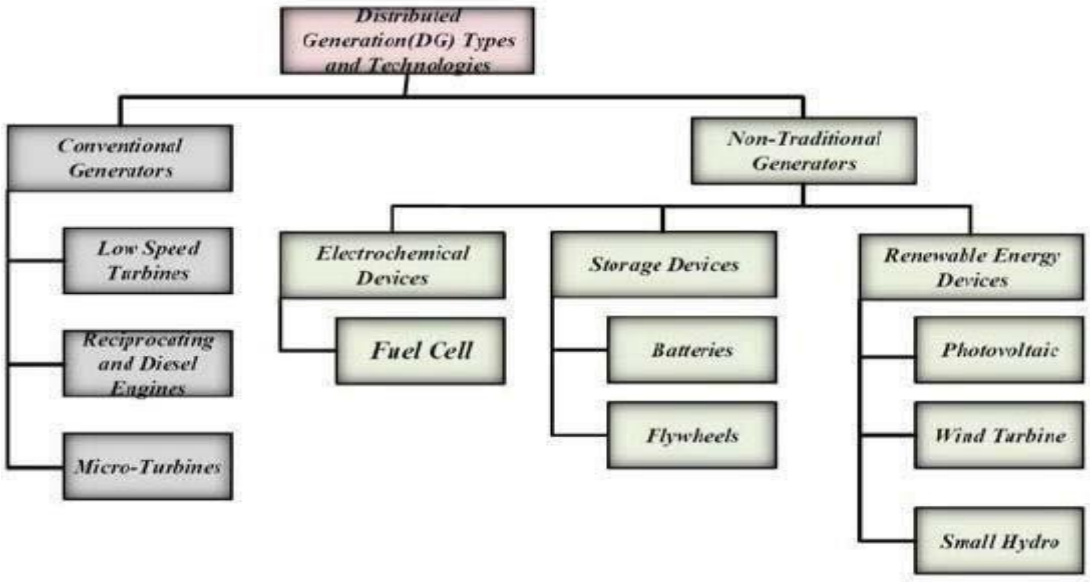

Figure 1.1 Classification of DG and technology used [9]

1.5 Outline of the Thesis

Based on the research work as explained in the previous section, the outline of the thesis chapter will be:

Chapter 2: Preliminary Theory This chapter deals with a brief discussion on types of micro grid.

Chapter 3: Literature Review This chapter deals with the review on the research that has been done till date.

Chapter 4: Design of Micro grid

This chapter deals with the design of energy resources like wind power source, solar power source, aqua electrolyzer, fuel cell, battery and fly wheel

Chapter 5: Result & Discussion

It analyzes the simulation results for different load variations in a micro grid.

Chapter 6: **Conclusion & Future Scope**

It outlines the conclusion and future scope of work.

CHAPTER2

LITERATUREREVIEW

Following papers are reviewed and studied for the implementation of the hybrid micro grid system.

- Micro grids are emerging as one of the promising solutions to integrate various types of distributed renewable energy sources with the utility grid. Though the existing grids are AC grids, today's electrical loads comprising of power electronic based equipments and distributed renewable energy generation make DC micro grids more attractive.

  However, an individual AC micro grid and DC micro grid requires multiple conversions of power at the user end for DC loads and AC loads respectively, resulting in less efficient system. Thus, hybrid AC/DC micro grid seems to be the best solution to avoid substantial energy losses in multiple conversions. However, there are several technical challenges in the implementation of hybrid AC/DC micro grid, which need to be addressed. This paper presents an overview of hybrid AC/DC micro grid and discusses the important key issues and challenges to be overcome for its practical implementation. [13]

- The increasing deployment of distributed generation systems in power systems hybrid AC/DC micro grid. Many micro grids are used for interlinking ac/dc converter with proper power management and control strategy. During the islanding operation of the hybrid AC/DC micro grid, the IC is intended to take the role of supplier to one micro gridand at the same time acts as a load to other micro grid and the power management systemshould be able to share the power demand between the existing ac and dc sources in both micro grids. This paper considers the power flow control management issues among the multiple sources dispersed throughout both ac and dc micro grids. The new method is proposed which is the decentralized power sharing method in order to eliminate the need for any communication between distribution generation or micro grids. This hybrid microgrid allows different ac or dc loads and sources should be flexibly located in order to decrease the required power conversions stages and hence the system cost and efficiency.

The decentralized control operation and droop control method is used for better control strategy. The performance of the proposed power control strategy is validated for small signal stability analysis and different operating conditions, using simulation studies in MATLAB software. [14]

- A DC micro grid system has been proposed as a power network that enables the introduction of a large amount of solar energy using distributed photovoltaic generation units. To test the feasibility of the system, we have developed a demonstration facility consisting of silicon photovoltaic (Si-PV) units, copper indium gallium (di) selenide photovoltaic (CIGS-PV) units, concentrator photovoltaic (CPV) units, an aero generator, and a redox flow battery. The redox flow battery, a key component for supply-demand adjustment in the micro grid system, successfully balanced supply and demand in the grid by its rapid charge-discharge ability even under the fluctuating condition of power generation and consumption.[15]

- This paper proposes a new DC micro-grid system, which fully utilizes the renewable energy and electric vehicle for smart energy delivery. The proposed DC grid incorporates the AC supply module, standby energy module, renewable energy module, and storage energy module together, to execute the energy distribution. Hence, this grid system can offer a high quality power for the three types of loads, namely 110V AC single-phase output, 48V DC output, and 100V DC output. The control strategy of the grid system for performing smart energy delivery will be discussed in the full paper. The simulation results will be also given to verify the four operation modes of the grid system. [16]

- This paper discusses a brief history of electricity, specifically alternating current (AC) and direct current (DC), and how the current standard of AC distribution has been reached. DC power was first produced in 1800, but the shift to AC occurred in the 1880's with the advent of the transformer. Because the decisions for distribution were made over 100 years ago, it could be time to rethink the standards of power distribution. Compared to traditional AC distribution, DC micro grids are significantly more energy efficient when implemented with distributed generation. Distributed generation, or on-

site generation from photovoltaic panels, wind turbines, fuel cells, or micro turbines, is more efficient when the power is transmitted by DC. DC generation, paired with the growing DC load profile, increases energy savings by utilizing DC architecture and eliminating wasteful conversions. Energy savings would result from a lower grid strain and more efficient utilization of the utility grid. DC distribution results in a more reliable electrical service due to short transmission distances, high service reliability when paired with on-site generation, and efficient storage. Occupant safety is a perceived concern with DC micro grids due to the lack of knowledge and familiarity in regards to these systems. However, with proper regulation and design standards, building occupants never encounter voltage higher than 24VDC, which is significantly safer than existing 120VAC in the United States. DC Micro grids have several disadvantages such as higher initial cost due, in part, to unfamiliarity of the system as well as a general lack of code recognition and efficiency metric recognition leading to difficult certification and code compliance. Case studies are cited in this paper to demonstrate energy reduction possibilities due to the lack of modeling ability in current energy analysis programs and demonstrated energy savings of approximately 20%.[17]

- Renewable power generation and the prospect of large-scale energy storage are fundamentally changing the traditional power grid. Arising challenges occur in terms of energy management, reliability, system control, etc. Micro grid, as an active subsystem of modern power grid, has revealed its promising potential in dealing with intermittent clean power generation and emerging energy storage, partially brought by electrical vehicle batteries. In this chapter, the concept of micro grid is introduced. The main focus is placed on the basic issues of control, operation, stability, and protection of DC micro grids.[18]

- Three-phase AC power systems have been in dominant position for over hundred years due to invention of transformer and the inherent characteristic from fossil energy-driven rotating machines. However, the gradual changes of load types and distributed renewable generation (DRG) in AC local distribution systems provide food for consideration of adding DC networks. Renewable sources such as fuel cells and solar photo voltaic are DC inherent and should be connected to AC grid through DC/AC

conversion techniques whereas some AC inherent renewable sources like wind generators also need DC links in their conversion systems to increase efficiency and mitigate power variation caused by intermittency and uncertainty. The disadvantage of AC grids for connection of DC inherent sources and loads as well as AC loads with DC links is that additional DC/AC or AC/DC converters are required, which may result in efficiency loss from the reverse conversion. In the other hand DC grids are resurging due to the development and deployment of renewable DC power sources and their inherent advantage for DC loads in commercial, industrial and residential applications. The number of power conversions in a DC micro grid has been significantly reduced to enhance system energy efficiency. A more likely scenario is the coexistence of both. [19]

- This paper presents a hybrid AC/DC micro grid concept to directly integrate DC/AC renewable sources and loads to DC/AC links respectively. The hybrid grid eliminates multiple DC-AC-DC&AC-DC-AC conversions in an individual AC&DC grid. The hybrid grid increases system efficiency, eliminates the embedded AC/DC and DC/DC converters in various home, office and industry facilities which can reduce size and cost of those facilities. The basic architecture of the hybrid grid is introduced in this paper. Different operation modes of the hybrid grid are discussed. The various control algorithms are investigated and proposed to harness the maximum power from various renewablesources, to store energy surplus during low peak loads, to eliminate unbalance problem inAC link, to maintain voltage stability and smooth power transfer between AC and DC linksunder various generation and load conditions. A prototype of the hybrid grid under construction is presented. Some simulation and test results are presented.[20]

- Considering the advantages of DC micro grids, the extension of the conventional AC distribution grid can be implemented using a DC micro grid. This justifies the realization of a hybrid AC/DC micro grid. In the present study, a new global solution is presented to improve the power quality and to fully compensate the reactive power of an AC micro grid using DC bus capacity while introducing a new design for a hybrid AC/DC micro grid. In the new design, back to-back connections of two series and parallel converters, as well as the presentation of new controllers and simultaneous utilization of an earthing switch, are proposed. The proposed method guarantees the quality of the delivered

voltage to consumers and the drawn current from the network according to the IEEE-519 and IEEE-1159 standards under different power quality problems (e.g., interruptions, sags, harmonics, and any variation in voltage/current signals from pure sinusoidal). Through the proposed design of the new hybrid AC/DC micro grid, as a new feature, the operationof the network in islanded mode can be achieved in accordance with power quality standards even in the worst load quality conditions. It should be noted that in common hybrid micro grids in islanded mode, the delivered voltage quality is proportional to the quality of the consumer's load current. Another possibility of the proposed design is the instantaneous VAR compensation of nonlinear and induction loads of consumers to keepthe power factor of the distribution transformer close to unit value. Simulation results indicate that there are acceptable levels of compensation for different types of power quality problems. Total harmonic distortions and total demand distortions are below 3% in both the grid-connected and isolated modes of the hybrid AC/DC micro grid. [21]

- This paper proposes real-time Energy Management System (EMS) for a residential hybrid ac/dc micro grid. The residential micro grid is organized in two different distribution systems. A dc distribution bus which interconnect the renewable energy sources (RES), energy storage systems (ESS) and the building's common facilities; while the apartments are supplied by an ac distribution system connected to the grid. This architecture avoids any modifications in the electrical installation that supplies energy to the apartments. A pure dc voltage supply is not yet a feasible approach for residential buildings. This architecture increases the overall efficiency of the distribution by interconnecting the RES and ESS thorough a dc distribution bus, and therefore avoiding unnecessary dc/ac conversion stages. The real-time EMS performs a 24 hours ahead optimization in order to schedule the charge/discharge of the ESS, and the energy injection/consumption from the grid. The EMS estimates the RES generation based on the weather forecasting, together with stochastic consumption modelling of the building. The EMS architecture and the residential micro grid have been implemented and tested in a laboratory scale setup. The results have shown how the operational costs of the system are effectively decreased by 28%, even with non accurate estimation of the RES generation or building parameters. [22]
- Complex circuitry of electronic infrastructure of compact micro-grids with multiple

renewable energy sources feeding the loads using parallel operation of inverters acts as a deterrent in developing such systems. This paper deals with applicable techniques reducing the driving circuits in parallel power inverters used in micro grid system (MGS), mainly focused on the distributed generation (DG) in islanded mode. The method introduced in this paper, gives a minimal and compressed circuitry that can be implemented very cost-effectively with simple components. DC micro grids are proposed and researched for the good connection with DC output type sources such as photovoltaic (PV), fuel cell, and secondary battery. In this paper, the electronic infrastructure of micro-grid is expressed. Then discussed the reasons for its complexity and the possibility of reducing the elements of electronic circuits are investigated. The reason for this is in order to compact DC micro-grid system for electrification to places like villages. Digital Simulation in Matlab Simulink is used to show the effectiveness of this novel driver topology for parallel operating inverters (NDTPI).[23]

- It presents design and analysis of optimized grid-tied solar PV/fuel cell hybrid power system to meet the electric loads of a commercial Building (Administration Building at the University of Sharjah) in this paper. The building AC primary loads were determined from the building energy audit. The renewable resources in Sharjah, the renewable energy technology options, the system component costs, and the constraints were determined. An integrated modeling, simulation, optimization, and control strategies were used to test the performance and the cost of the proposed grid-tied hybrid solar PV/fuel cell power system. The effect of the solar PV power capacity on the performance (renewable fraction, cost of energy and greenhouse gas emissions) of the grid-tied solar PV system was investigated. The results show that the solar grid-tied solar PV/Fuel Cell grid power systemmeets the daily and yearly electrical demand of the building with some of the excess power (from the solar PV and fuel cell) sold back to the grid. The grid-tied solar PV/fuel cell hybrid power system offers a good penetration of renewable resources (40.4% renewable fraction), low levelised cost of energy (71

  $/MWh), and low carbon dioxide (CO2) emissions (133 kg CO2/MWh). The integration of renewable power systems with the utility grid is one of the best strategy and efficient method to increase the penetration of renewable energy in the energy mix with affordable cost of energy, reduce the reliance on fossil fuels and reduce the environmental impacts (greenhouse gas emissions reductions).[24]

- It presents an approximate 73kW hybrid micro-grid system designed with PV, FC, and battery storage system. In order to test the system's performance in off-grid mode, a 43kW ac load is connected to the proposed system via a dc/ac inverter. It is shown that the system yields stable output voltage and current. Moreover, the stability of the system is validated by connecting it to the IEEE 13 bus system, and an approximate of 73kW real power is added to the grid. Under this on-grid mode, the proposed system also remains stable. Hence, the proposed hybrid micro-grid system may be the future solution for the ongoing power crisis in the universe. [25]
- It report a systematic literature review of control aspects in ac, dc, and hybrid ac-dc micro grid. There has been an extensive volume of research on the various aspects of the micro grid. The control aspects of the micro grid are the most studied topics of interest. Without a stable and accurate control, the micro grid implementation is not feasible. Although ac micro grid has been a widely researched topic, dc and hybrid ac-dc micro grids are gradually gaining interest of the researchers from the perspective of reliability, minimization of converter losses, and efficiency. The control hierarchy of the three categories of micro grid follows a similar pattern, while the difference lies in the droop characteristics involved in the primary control, and the application of secondary and tertiary control for different operating modes in them. The heart of the micro grid control is the EMS in the case of centralized approach. Once the central controller fails in its operation due to the communication error, the primary controllers too cannot be functional. However, in case of decentralized secondary control, there is no need for a centralized controller's command to operate primary controllers. The decentralized secondary control is less reliable than the centralized one, as the LCs cannot function optimally due to the lack of information about the system operating state. [26]
- It presents The performance of UPQC under different load conditions has been studied and compared with micro grid side disturbances and grid side disturbances, it is observed that the harmonics in load current is reduce below 5% in all cases and also the compensation of voltage sag and swell. The simulation result shows that UPQC connected to grid with nonlinear load can compensate voltage sag, swell and also reduce the load current harmonics to 2.33%. The implementation of micro grid with UPQC makes an advantage that it can compensate all the power quality and also reduce the load current harmonics to 3.48%. From the analysis it is found that UPQC connected to utility

and micro grid can compensate all the PQ issues in distribution side. Moreover, in case of any major fault or power disturbance in the main grid, the Micro grid switches over to stand-alone mode while still feeding power to the critical loads effectively.[27]

- It presents a paper concerned with the design of an autonomous micro grid system intended for use in a residential application. For ensuring a highly accurate solution, the loads were analyzed and appropriate load curves were constructed for a 12-monthperiod.The primary objective was the minimization of the total NPC of the overall system, whileno load shedding was allowed amongst a few other technical constraints. The optimization procedure evaluated thousands of design choices ranging from various capacities of the selected energy resources and converter as well as two types of batteries combining different technical characteristics and capital costs. The analysis concluded that, for the given loads, the best system design is the one comprised of a PV array with a capacity of 15.3 kW, a 17 kW diesel generator, 57 kWh of lead-acid batteries, and a converter with a power rating of 6.93 kW; the total NPC of this system equals £56,264. Additionally, the carbon emissions were calculated, and the study indicated that the optimal system design corresponds also to the system with the least carbon emissions; this is a non-negligible factor towards improving the environmental conditions. The optimal solution supports the argument that, for such applications with no possibility of grid connection, a hybrid system constitutes a cheaper and environmentally friendly solution compared to the solution comprising of a standalone diesel generator. Additionally, a sensitivity analysis relating to diesel prices and solar irradiation was performed. The analysis concluded that these two parameters are characterized by an inversely proportional relationship, while showing that diesel fuel price increase leads to an increase of the PV array and converter rating. [28]
- It reports design and control of a standalone micro-grid system with a PV system and WECS were proposed in this work. To control and harvest the most power possible from the PV system, fuzzy logic-based MPPT was used for a boost converter. The PV system's output provided a constant DC bus voltage to a battery storage system that was regulated by two PI voltage and current control loops. The control system is intended to achieve the load in all cases. When the energy generated by the PV panel exceeds the energy required by the load, the excess energy is used to charge the batteries. When the PV panel's electricity is inadequate to fulfill the load's demands, the extra power is

drawn from the charged batteries. Furthermore, the controller is employed to protect the battery banks in all scenarios, including normal, overcharging, and over discharging scenarios. Each case should be handled appropriately by the controller. Regardless of the battery's state of charge, the controller performs as expected under normal operating conditions (20% < SOC < 80%). A specific order is delivered when the SOC hits 80%, which turns off the PV panel and the wind turbine. The PV panel and wind turbine cannot be connected until the SOC drops to a safe margin of 75% in this controller. Other commands are sent out to turn off the inverter and disconnect the loads when SOC falls below 20%. The inverter's power is switched off until the batteries are charged again to a suitable value. The designed stand-alone micro grid system and their controllers solved the problem of supplying the electric energy to remote areas where the electrical grid does not exist. [29]

- They study's main objective is to ensure stable DC bus voltage by providing an effective system for DC micro-grid powered by a fuel cell and solar panel, and the backup storage unit (SC). The parallel employment of PV and FC ensure to the load is sustainable supplying. The research focuses mostly stabilizing the DC bus voltage, moreover, employing the FC, solar panel and SC in the energy management approach, taking into account the energetic properties of these sources such as its power and energy density and its dynamics. Nonlinear differential flatness strategy for DC micro grid based on a renewable source with a fuel cell provides excellent DC-link stabilization. The super-capacitor can move the load forward, regarding the characteristics of the main sources, by supplying a stronger power response to the load. During the important steps of the load, the super-capacitor offers the energy balance required during the transition of the load. Also, distributed power systems improve power quality and efficiency.[30]
- This paper has dealt with the optimal design of hybrid AC/DC MGs. A tailor-made GA has been proposed to solve the design problem with relative computational simplicity, while a detailed AC OPF with the ability to capture contingencies has been utilized to evaluate the design candidates determined by the GA. This approach provides a benefit over other design tools found in the literature, as it ensures that the optimal design candidate satisfies all operational constraints of the MG. A generalizable AC/DC MG has been utilized for demonstrating the benefits of the approach. Additionally, through appropriate simulations the paper indicates the benefit in cost savings of utilizing

different types of storage devices (i.e. a mix of high/low power-energy) and appropriately discriminating loads into critical and non-critical. As future work, since the problem under investigation is that of optimal design, it is necessary to consider a much longer planning horizon (i.e. at least several representative days/weeks) to ensure that the system is not oversized due to using a peak day. It is also of paramount importance to capture within this planning horizon the effects of stochasticity both for loads and natural resources. To achieve this, it is anticipated that an appropriate decomposition method, splitting the problem into two sub problems (i.e. one per sub grid) would allow a much longer horizon to be simulated with considerably less computational expense.[31]

- They proposed a micro electrical power grid system composed of an optimal controller design using an MBA algorithm. This studied controlled power system mainly includes hybrid wind/fuel cell generation unit which feeding both dynamic and static loads. These loads are fed by the fuel cell and the wind power generation system. At high values of wind speed wind power acts as the master source that supplies the loads and store hydrogen in the FC via the electrolyzer. Consequently, at low values of the wind speed, the FC acts as a slave that supplies the loads. The proposed micro grid system is simulated using Simulink/MATLAB software and is tested in step variations of wind speed, IM rotor speed, IM torque, and static load current. The results of the simulation show that the proposed generation system success to supply the loads perfectly under all disturbances. It is indicated that the performance of the main inverter controller is excellent, as the load power responses have low overshoot accompanied by small settling time.[32]

CHAPTER 3

CLASSIFICATION OF MICRO GRID

3.1 Overview:

Micro grids are classified as AC systems, DC systems or Hybrid systems based on the power drawn from it. Any of these typical micro grid is identical to a small power system consisting interconnected components like DG units, loads and storage devices. Although controlling large number of DG's is challenging considering the safety and efficiency of the system, modern technology plays a crucial role in overcoming these problems using power electronic devices which interfere with DG's to create an architecture called as micro grid. As discussed earlier the components of micro grid are connected to power distribution network using point of common coupling and thereby it appears as a single unit to the entity. The classification based on power type is shown below:

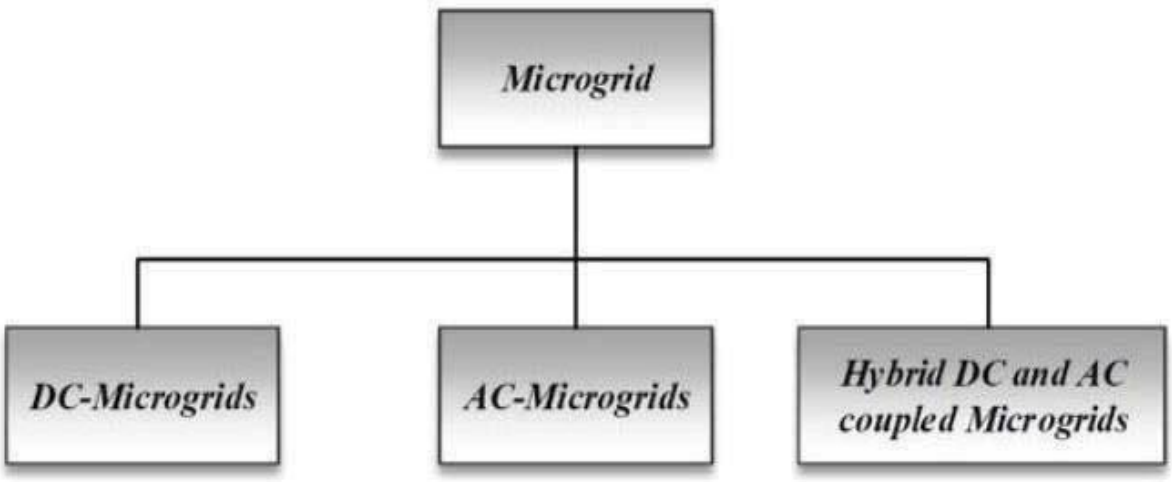

Figure 3.1 Classification based power type: AC or DC micro grid [10]

3.2 DC Micro grid:

Recently DC micro grid has a rising popularity in coming years and provides most attractive options over AC micro grid structure. DC micro grid inherits two modes of

operation: grid-connected mode and autonomous mode and has several advantages of AC micro grid.

DG system in MG's mostly consisting of PY units, fuel cells Wind turbines or any other renewable energy resource. It utilizes the dc output voltage from its storage devices and thus its utilization can be easily carried out by help of voltage regulator. There is no need of additional synchronization system for to match the voltage magnitude, phase or frequency as needed for AC systems. Thus because of better compatibility, higher efficiency and better stability & reliability DC micro grid is an emerging option in micro grid technology.

A typical example of DC micro grid is as shown below:

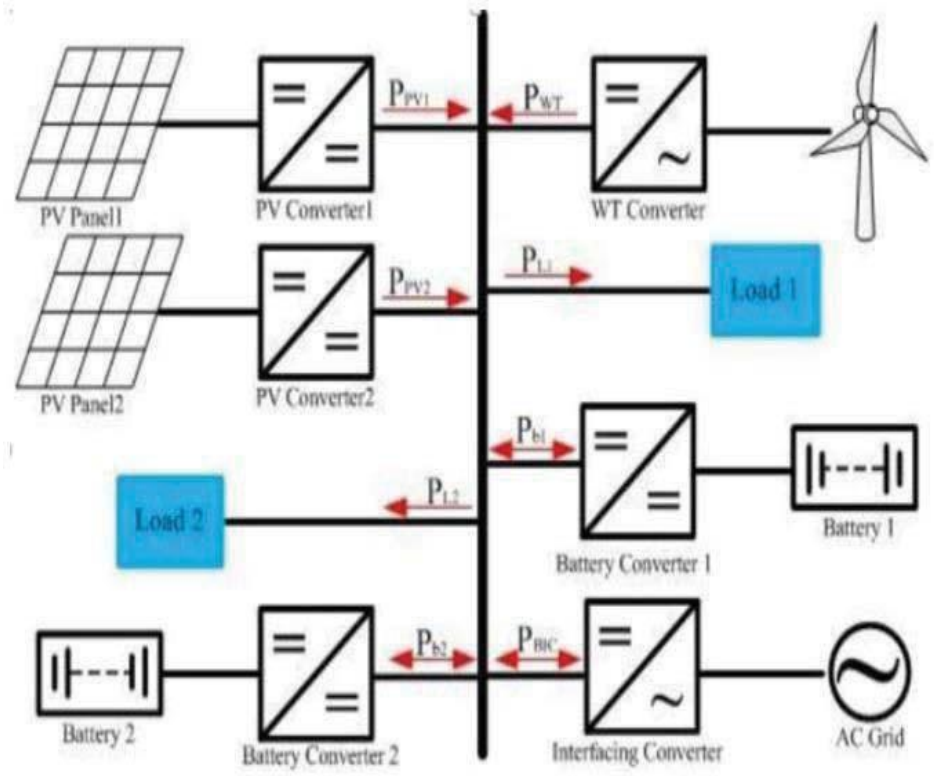

Figure 3.2 Structure of basic DC Micro grid [11]

As seen, the PV panels are connected to the DC bus via DC/DC converters and the wind turbine is connected using an AC/DC rectifier. Also two battery units acting as power storage element are used to store excess power by help of DC/DC converters; this allows charging and discharging as and when required. As seen by making use of interfacing converters the load can be supplied to the AC grid.

3.3 AC Micro grid:

Although DC micro grids were widely preferred initially because of its easy utilization, AC micro grids have won over DC systems for several reasons. AC system can easily alter the voltage levels thereby providing flexibility to the generation, transmission andconsumption side. Also the cost of AC equipment is relatively cheaper than DC equipment. As AC distribution network is predominantly preferred worldwide, integration of AC micro grid in distribution network adds excellent benefit to the conventional power system.AC micro grid can be utilized and extended to rural as well as in cities and thereby generatereliable power in case of occurrence of any disturbances. Thus it can also be easily operablein off grid mode.

A basic example of micro grid is as shown below:

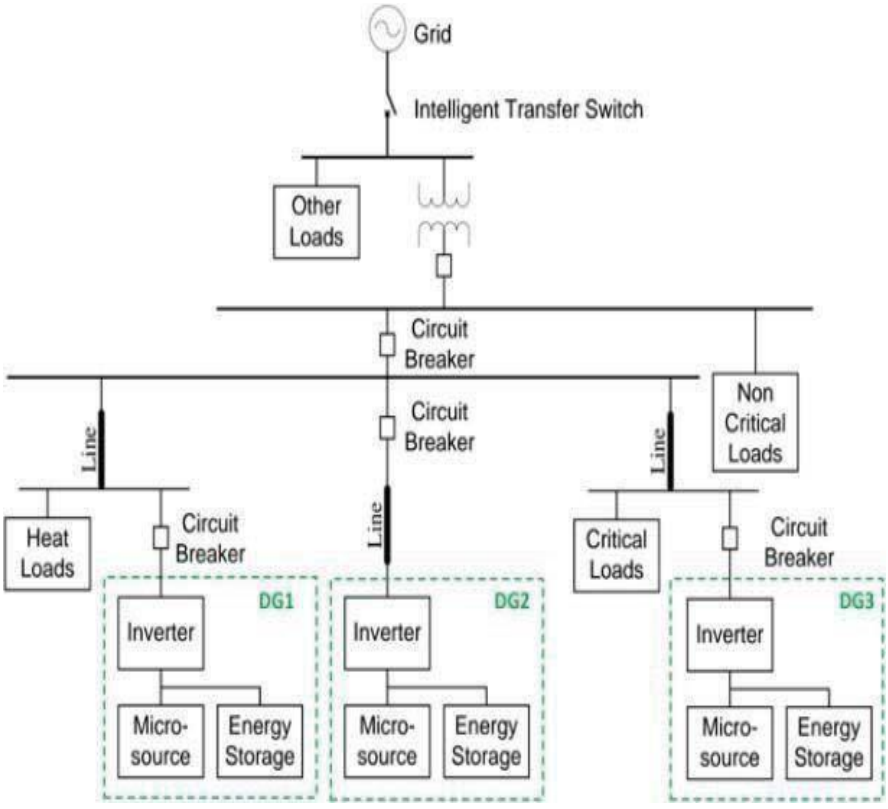

Figure 3.3 Structure of basic AC Micro grid [11]

From the typical example shown above it can be seen that the micro grid is connected to the mains using an intelligent transfer switch, which allows the MG to operate in grid connected as well as off grid mode. As seen in the figure each DG consist of inverter

systems, a micro-source typically photovoltaic, wind turbines and fuel cells etc. and energy storage systems. This type of micro grid structure makes less losses and flexibility in power supply.

3.4 Hybrid AC/DC Micro grid:

Although dc micro grid have many advantages over AC micro grids, this technology is not yet accepted completely and is not enough to change the existing system drastically. Since AC system is predominantly into existence therefore it is more likely that a combination of AC & DC micro grid system can solve the existing problems in efficient way. Thus the reasons for using hybrid concept for micro grid are as follows:

3.1.1 Load tendency from AC to DC:

The power supply system is designed to supply residential, commercial & industrial loads. Initially the ac and dc loads and generators were designed such that they can adapt to both AD and DC system as whole but very complicated and inefficient system had to be installed eventually suffering heavy losses. Later on AC systems became standard and dominant source for energy supply in all sectors, since then everything was designed keeping AC system and its shortcoming in mind. Also, the DC loads were still being used by connecting them with AC/DC converter neglecting the efficiency of such converters.

The development of power electronic devices and its control techniques has led to change in load tendency from AC to DC because now it's possible to achieve higher efficiency, flexibility and reliability in implementing the DC systems. The change is also taking place as most of the modern electrical equipment and power systems make use of DC system for their operation, e.g. computers, printers, home theaters, refrigerators, air conditioners, washing machines, commercial buildings. On the other -hand, many devices make use of AC/DC converters for their operation to adjust the speed and save energy. Also the modern technology is inclined towards creating energy efficient devices which mostly makes use of DC components and systems. Therefore, DC loads can be now efficiently utilized and integrated with exiting AC systems.

3.1.2 Recent trend of renewable energy resources:

With the growing research in RES 3.technology such as PV systems, Wind turbines, Energy storage system, fuel cells and tremendous demand for energy is the reason for looking at alternative options to supply energy efficiently to the increasing population.

Thus there is increase in utilization of DC systems in existing AC power systems and up gradation leading to hybrid technology coming into existence.

3.1.3 Power conversion in AC and DC systems:

The power conversion in AC and DC can be analyzed as follows:

When PV system, Fuel cells are integrated into AC systems there is a need for DC/AC converter so as to supply the power into AC system. Other than that DC power can alsobe directly utilized for DC operating systems.

When AC power is generated it need not be converted in order to be supplied to the AC load. This minimizes the conversion cost and makes the system easy to use. When DC loads are connected to such system rectifiers are used such as DC-AC-DC-AC along withDC/AC inverters.

In DC systems, no DC conversion is required for DC loads and the power consumed by the system is DC. If DC sources are consumed by AC system, then conversion from DC- AC or AC/DC is required as per specification of the system.

3.1.4 Mode of operation of Hybrid micro grid:

The operating modes of hybrid micro grid are based on the type of topology used and flow of power in the system.

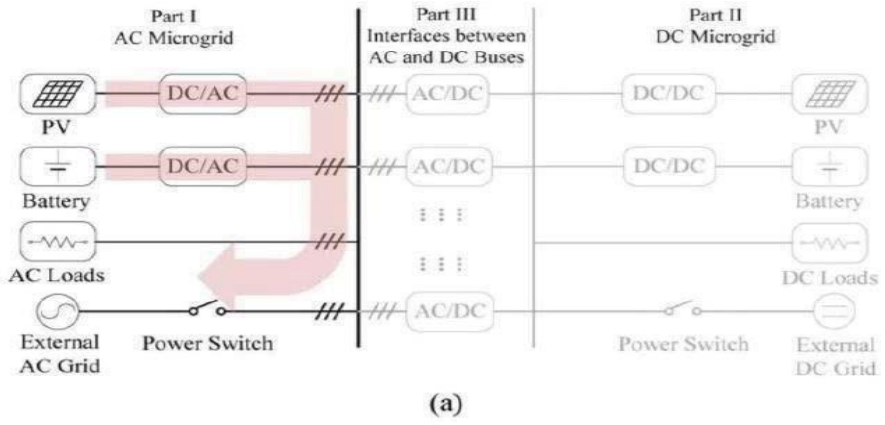

Figure 3.4 Operation of AC Micro grids [12]

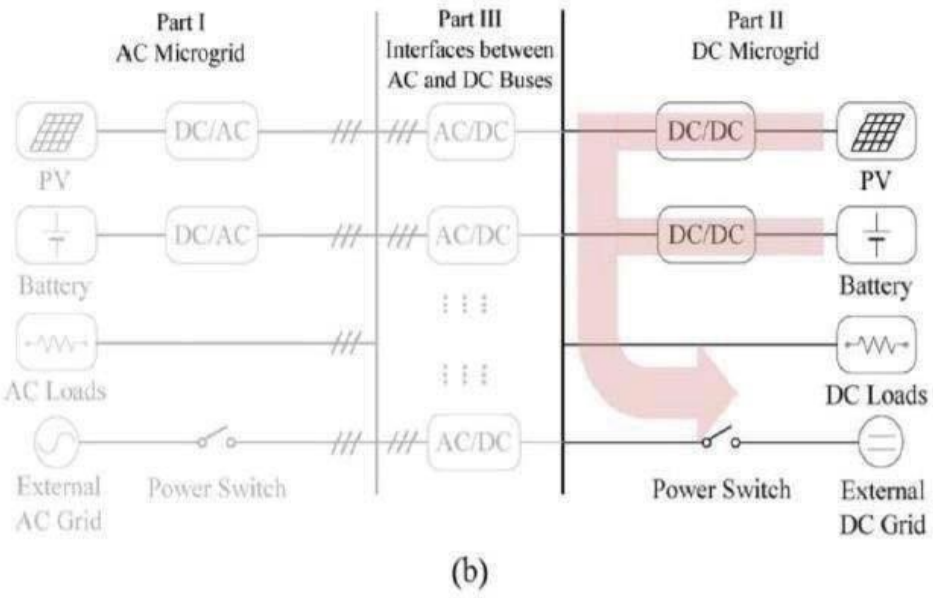

Figure 3.5 Operation of DC Micro grids [12]

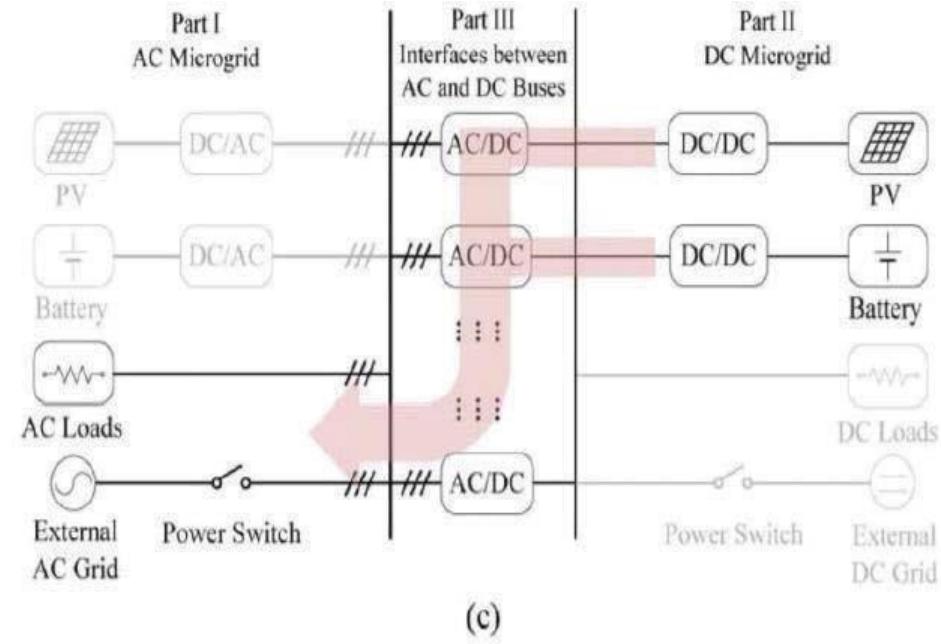

Figure 3.6 Operation of Hybrid Micro grid: DC to AC flow [12]

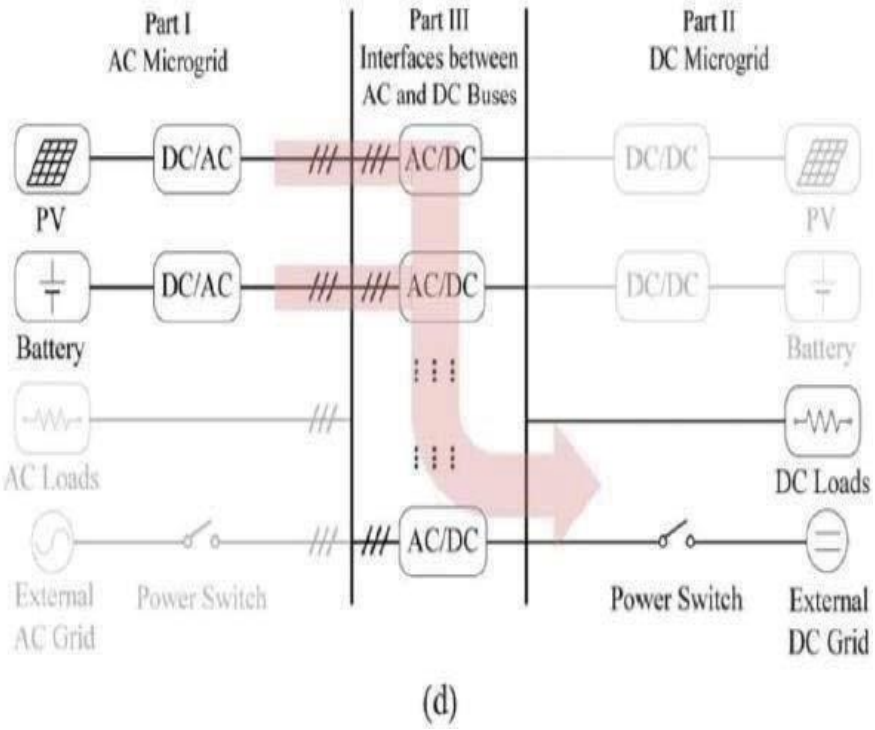

Figure 3.7 Operation of Hybrid Micro grid: AC to DC flow [12]

As seen in figure (a) and (b) the system is working as pure AC and pure DC micro grid respectively. In figure (c) & (d) shows interfacing between AC and DC systems.

In figure (a) only the AC sources are working and supplying power to AC load. There is no connection with the DC micro grid and its interconnecting bus bars. Also when needed it can share power to the external AC grid. In Figure (b) only the DC sources are working to supply power to DC load. It has no connection with AC micro grid and its interconnecting bus bars. Similarly, it shares power to the external DC grid. In Figure (c) depict that the DC sources are in connection with the interfacing bus bars to supply AC load and also share power to the grid. This concept shows a type of hybrid technology. Figure (d) is for the AC source is connected to the interconnecting bus bars to supply DC load using AC/DC converter. Also it shares power to the DC grid as and when required.

Chapter 4

DESIGN OF MICRO GRID

4.1 General Structure of Micro grid

This islanded micro grid is composed of the DG, the distribution network, the control system and the load. More specifically, the distributed generators are composed of the Photovoltaic (PV) system and the wind turbine system so this micro grid uses renewable energy as the resource. Both the PV system and the wind power system have their own control system. The general structure of the micro grid is shown in the Figure below:

Figure 4.1 Structure of the Micro grid

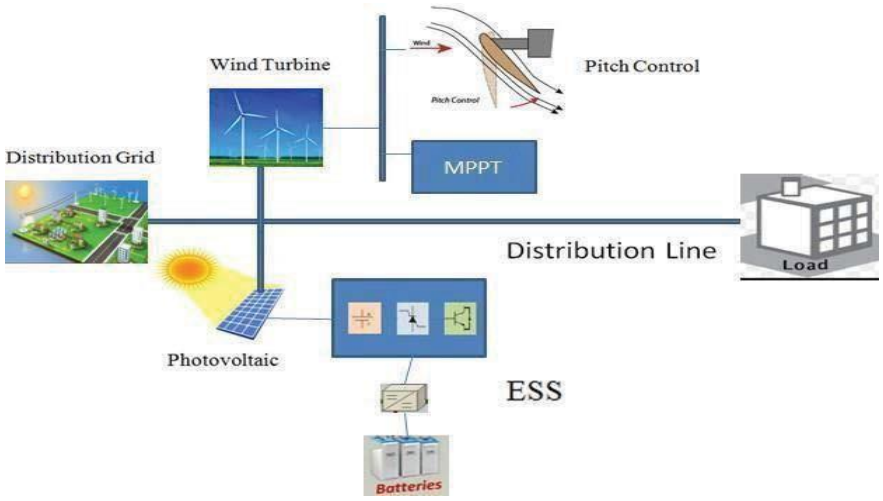

Figure 4.1 shows the basic structure of the micro grid, which includes the Distribution grid, the wind turbine equipped with the pitch controller and the MPPT controller, the Photovoltaic, the energy storage system, the battery, the distribution lines and the load. The distributed generators use wind and solar as resources. The ESS which includes the converter and the battery is used to supply or assimilate power. In terms of the control of the wind power system, the pitch controller and the MPPT control are included. Finally, the distribution lines and the load are also added as the indispensable components of the micro grid.

In terms of the PV system, each solar panel is comprised of a number of solar cells that

generate electric power [33]. PV panel converses light into electricity and it produces no pollution; this technology has been used since half a century ago and is getting cheaper and more efficient nowadays. The PV system also includes the converter that connects the panels and the inverter. Furthermore, an energy storage system is also built to provide power to the load when there is no sunlight and the irradiance becomes 0.

Wind turbine converts kinetic energy of the wind into electric power and it can be manufactured in both vertical and horizontal axis types [33]. The small and medium sized wind turbines are used for applications such as battery charging for auxiliary power for boats or supplying domestic power while selling unused power back to the utility supplier via the electrical grid [34]. Arrays of large turbines, known as wind farms, are used as the main source of renewable energy and are used by many countries as the replacement of fossil fuels and oil [35].

Since most of the wind plants in the micro grid are composed of variable-speed and horizontal axis wind turbines, this thesis also choose the same type (variable-speed and horizontal axis) as the wind turbine.

The block diagram of micro grid in details is shown in figure 4.2 as below:

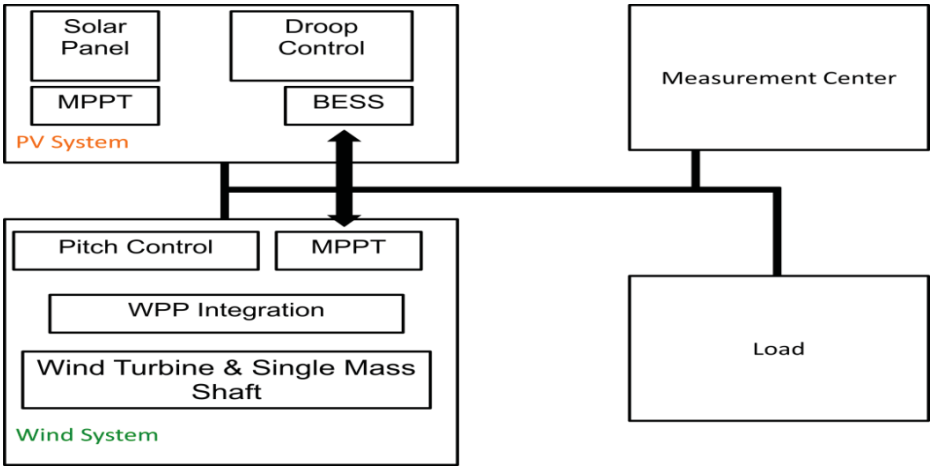

Figure 4.2 Block Diagram of the Micro grid in Details

This is the architecture of the micro grid system and it includes two distributed generators (PV and wind turbine). The battery energy storage system (BESS) of PV system and the MPPT of wind power system can communicate with each other so the micro grid can be controlled coordinately. This micro grid system can be connected or

disconnected to the distribution grid. When the distribution grid has been disconnected, the micro grid can provide power to the local load.

4.2 Specific Design of the PV System

The first step is to design the PV system. The block diagram structure of the PV system is shown in Figure 4.3 as below:

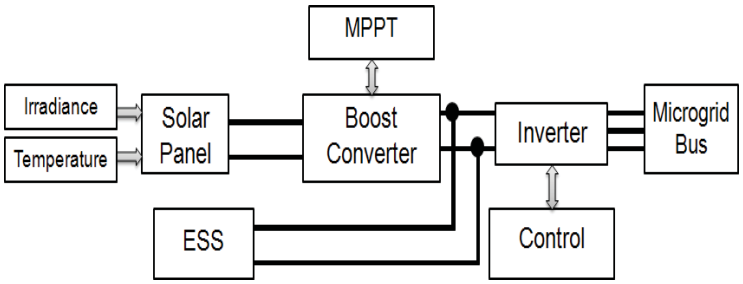

Figure 4.3 Structure of the PV System

The output of the solar panel is dictated by the solar irradiance and the environmental temperature. In this case, we assume the temperature is 15 degrees Celsius. The output solar panel the dc power into the boost converter so boost converter can regulate output solar panel based on the MPPT controller. Then the DC power is sent to the inverter system, which is controlled by the droop control system so the AC power is delivered to the micro grid bus. The battery energy system can be charged or discharged according to the solar panel output.

From Figure 4.3, it is clearly seen that the PV system is composed of the PV panel, the control system, the MPPT and the Energy Storage System (ESS). In MPPT, it tracks the maximum power output of the solar panel; droop controller decides the output power of overall PV system, and BESS can be charged/discharged based on the output power of the solar panel. When the PV panel cannot output

The equivalent circuit of the PV cell is based on the model as shown in Figure 4.4 as below:

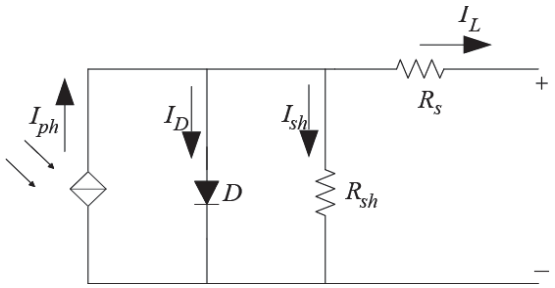

Figure 4.4 Equivalent Circuit of the PV Array

As the figure shows above, *Iph* is the photocurrent, *ID* is the current of the diode, *Rsh* is the shunt resistance and R_S is the series resistance, and I_{sh} represents the shunt current. Based on the photoelectric effect, the equation of *Iph* can be represented as below [36]:

$$I_{ph} = \frac{[I_{sc} + K_t(T - T_{ref})]S}{\lambda} \quad \textbf{(4.1)}$$

Where S represents the solar radiation, $I_{sc}$is the short-circuit current at the standard temperature. Kt represents the short circuit current temperature coefficient of the cell. T_{ref} is the reference temperature and $/l$ has the value of 1000 W/m^2. Based on the characteristics of diode, the equation of the I_D can be represented as (2.2) and the relation of the voltage and current of p-n junction can be represented as equation 4.3:

$$I_D = I_0(e^{\frac{qV}{AKT}} - 1) \quad \textbf{(4.2)}$$

$$V = I_{sh}R_{sh} + I_L R_s \quad \textbf{(4.3)}$$

Where q has the value of 1.6e-19 C and K = 1.38e-23. I_0 is the reverse saturation current. Based on equations 2.1, 2.2 and 2.3, the characteristic equation for the voltage-current of a solar cell is given as [36]:

$$I_L = I_{ph} - I_0\left(e^{\frac{q(V_{DC}+I_L R_L)}{AKT}} - 1\right) - \frac{V_{DC}+I_L R_L}{R_{sh}} \quad \textbf{(4.4)}$$

In order increase the capacity of the output power of the PV array, multiple photovoltaic cells are interconnected in parallel and series to have desired volt-ampere characteristics of the entire photovoltaic cell array. The revised equation is given as [31]:

$$I_L = N_p I_{ph} - N_s\left(e^{\frac{q(V_{DC}+I_L R_L)}{AKT}} - 1\right) - \frac{V_{DC}+I_L R_L}{R_{sh}} \quad \textbf{(4.5)}$$

Where$N_p$is the number of PV cells that are connected in parallel; $N_s$is the number of PV cells in series. Also, the cell's saturation current varies with the temperature of the cell as described in the equation shown below [36]:

$$I_S = I_{RS}(T_C - T_{ref})^3 * e^{qE_G(\frac{1}{T_{ref}}\frac{1}{T_C})/AK} \quad \textbf{(4.6)}$$

Where E_C is the band-gap energy of the semiconductor in the PV cell.

The boost converter is designed as a step-up converter that aims to increase the voltage to a higher output value. In this case, the output solar panel the DC power into the boost converter, so the boost converter can regulate output solar panel based on MPPT controller.

4.3 Battery Energy Storage System

It is very challenging to control and operate the renewable micro grid due to the variability and intermittency of distributed generators that use renewable energy.

Therefore, an energy storage system (ESS) is necessary in the PV system. The ESS can provide the specific voltage and frequency support for the islanded micro grid and it changes the power output to regulate the frequency and voltage to the scheduled values [37]. Therefore, the Energy Storage System plays a vital rule in stabilizing the micro grid. There are various types of converters in the Energy Storage System, such as DC- DC

and DC-AC converters. Since solar panel outputs DC power, a DC-DC converter is used in this case in order to change the voltage level. The buck-boost converter is indispensable because it is able to both charge and discharge the Battery Energy Storage System (BESS), therefore changing the direction of the power flow according to different situations. For instance, the voltage of the energy storage system will be stepped up when its voltage is lower than that of the micro grid side so that the battery energy storage system can discharge to supply power to the micro grid and vice versa [38].

In this thesis, the battery energy storage system consists of one buck-boost bidirectional converter and one battery; the structure of the converter is shown in Figure as below:

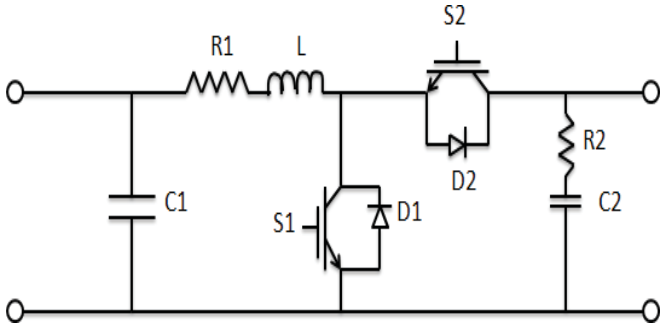

Figure 4.5 Structure of the Buck-Boost Bidirectional Converter

Power allocation is achieved by controlling the direction and value of the electrical power flowing through the bi-directional dc/dc converter. *C1* is the low- voltage side and *C2* is the high-voltage side.

As it is shown above, the inductance is 2.332 mH and the diode has the resistance of 0.001 ohm, forward voltage of 0.3 V. Both the MOSFET and internal diode have the resistance of 1 ohm. Basically, when MOSFET1 (*S1*) is switching, and MOSFET2 (*S2*) is kept on and it is the boost converter; the battery discharges the energy to the micro grid. When *S1* is OFF, *S2* is switching, it is the buck converter and the battery is getting charged [39].

The other component of the battery energy storage system is the battery. The battery type is the Lithium-ion in this case. One of the reasons to choose this type of battery is that Lithium-ion battery is a very popular type of rechargeable battery with a high energy density, tiny memory effect and low self-discharge [40]. The nominal voltage is

set to be 311 volts and the rated capacity is set to be 1000 Ah with the maximum capacity of 1077 Ah. Therefore, the battery has an appropriate capacity that is neither too large nor too small based on these values.

The output of the boost converter goes to the VSC, voltage source converter and the circuit is shown in Figure 4.6 as below:

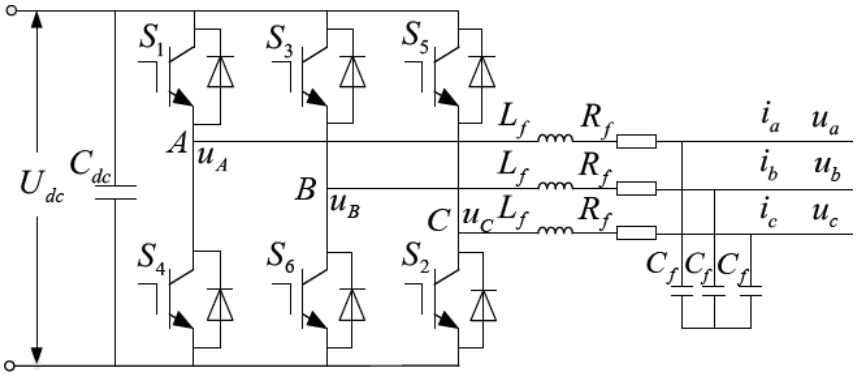

Figure 4.6 Circuit of the Voltage Source Converter

As the figure shows, there are six switches (S1 to S6) paired with six diodes in the three-phase voltage inverter. *Udc*is the direct output voltage from the solar panel, *Cdc* is the filter capacitor, *Lf is* the filter inductor and *Rf is* the filter resistance. *ua, ub, uc* represent the output voltages of the inverter and *ia, ib, ic* represent the output currents of the inverter.

4.4 Control System of PV

The control system of PV is also significant. The control system is expected to control the frequency, the output power and the voltage in the PV system. The structures of the PV control system are shown in Figure4.7:

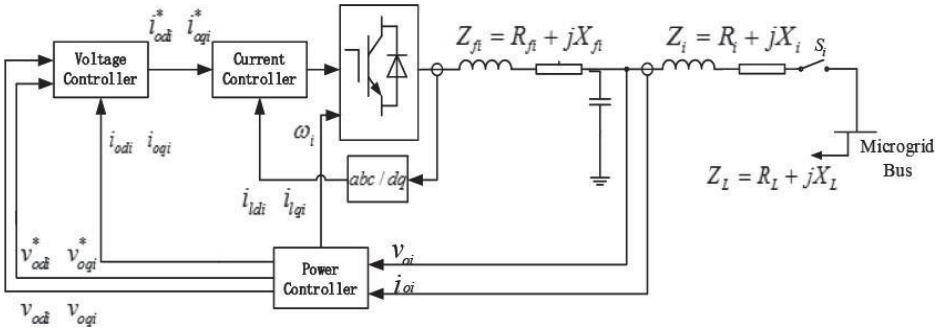

Figure 4.7 Structure of the PV Control System

As it is shown above, the PV control system calculates the power output of the VSC using feedback signals *V*abc and *I*abc, then droop controller can generate reference signal so the voltage and frequency of micro grid can be regulated. Then the reference signals are sent to the dual-loop PI controller in which the outer loop is voltage PI controller and the inner loop is the current PI controller. The dual-loop PI controller has the structures as shown below:

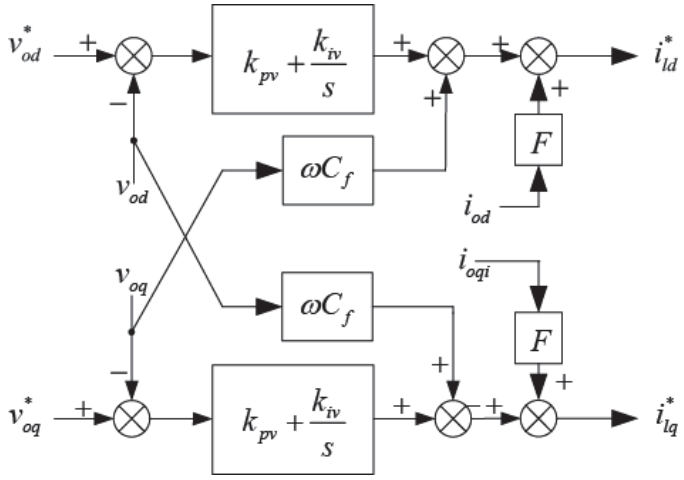

Figure 4.8 Structure of the Voltage Controller

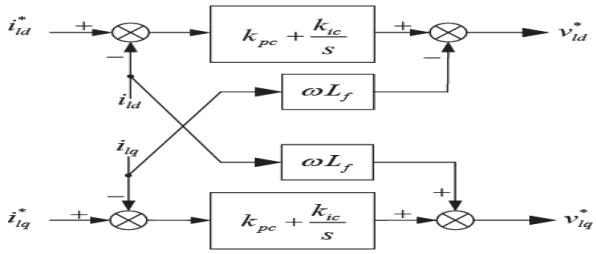

Figure 4.9 Structure of the Current Controller

There is coupling effect when converting the three-phase voltage and current of the VSC into the voltage and current of d-axis and q-axis, so the decoupling terms(wC_fv_{oq}, wC_fv_{od}, wL_fi_{lq}, wL_fi_{ld}) are added in the voltage and current controller [41].

4.5 Wind Power System

The second distributed renewable source is the wind energy conversion system (WECS). Variable-speed Wind Turbine Generator (WTG) is controlled by the power converter that is interfaced between the WTG and grid. There are two types of

variable- speed WTGs, doubly fed induction generator (DFIG) and permanent magnetic synchronous generator (PMSG). In comparison with a doubly fed induction generator, a PMSG-WTG has higher efficiency and reliability because it can be driven directly by a wind turbine since the rotating speed of the generator is slowed down with the multi-pole structure. On the other hand, the PMSG is also expensive for its high cost of converter [42]. Since this thesis focuses on the small-sized grid, the PMSG is used here as the type of wind turbine generator. The typical structure of the PMSG is shown in figure 4.10 as below:

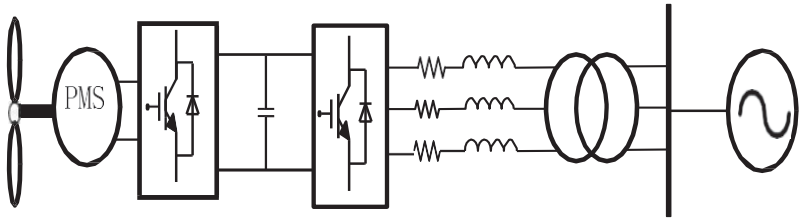

Figure 4.10 Structure of PMSG

In PMSG, the air gap flux is maintained by the permanent magnet and only the q- axis current decides the electrical torque because there is the d-axis current controlled to be 0 by the generator-side converter (GSC) [42]. In this thesis, the wind power system is composed of the wind turbine and single mass shaft, the Wind Power Plant (WPP) Integration, the MPPT controller and the pitch controller.

4.5.1 Wind Aerodynamic and Single Mass Shaft

The wind aerodynamic and single mass shaft has the structure as shown below:

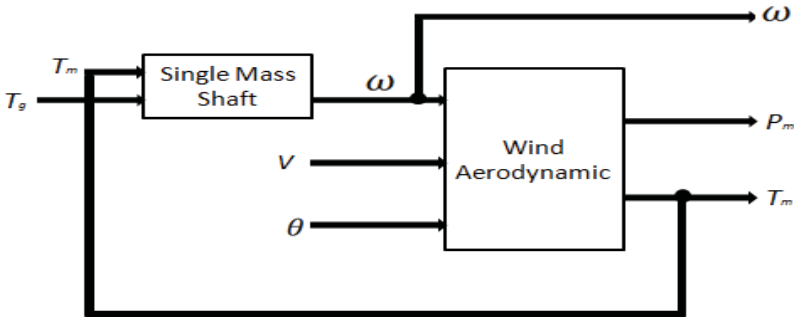

Figure 4.11 Structure of the Wind Aerodynamic and Single Mass Shaft

As it is shown in Figure 4.11, there are two conversion processes in the wind turbine generator. The wind turbine gets the torque from the pressure of the wind and the

mechanical torque is converted into electric power through the generator [42].

The single mass shaft is based on the equation below:

$$T_\tau - T_g = 2H\frac{dw}{dt} \quad \textbf{(4.7)}$$

The difference between the wind turbine torque and the generator torque is in proportional to *!Jw. H* has the value of 3 and then using the equation of rotor speed *!Jw +wO = w*, where *wO = 0.5* and is added to the speed to calculate the rotor speed, which is sent to the wind turbine.

The wind aerodynamic function is based on equation 4.8 as shown below:

$$P_m = \frac{1}{2}\rho\pi R^2 v^3 C_p(\lambda,\theta) \quad \textbf{(4.8)}$$

The power of the wind turbine is in proportional to the air density *(p)*, the area of the turbine blade (*rrR²*), the wind speed (*v*) and the power coefficient of the blade(*C_p(/l, 8)*). The air density is 1.225 *kg/m³*and radius of the blade is 39.26 m. The power coefficient is also related to the tip speed ratio (TSR) */l* and the pitch angle *8*; where */l* $= \frac{CR}{v}$. Therefore, it is necessary to adjust the turbine speed according to the wind speed In order to get the maximum power and conversion efficiency.

According to the Betz limit, the power coefficient of the blade has a theoretical maximum value of 0.59. Then the value of the power coefficient of the blade (*((/l, 8)*) is figured out by the value of */l* and the value of the pitch angle *8*.

The basic structure of the pitch controller is shown as below:

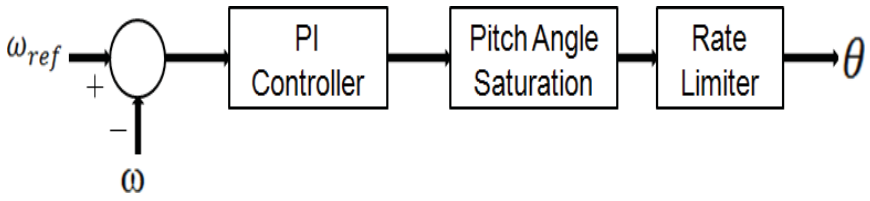

Figure 4.12 Structure of Pitch Controller

As it is shown from the Figure 3.3, the pitch controller is capable of restricting the rotor speed under high wind speed by turning the blade angle of attack and it is clamped to

the optimal value, which is set to be 0 degrees when the wind speed is below the rated value [43]. When the wind speed exceeds the speed of the rated value, the pitch controller increases the angle of the attack of the blade, therefore making the reduction in the lift force; when the blade is fully pitched, the pitch controller makes the blade angle of attack aligned with the wind so that the lift force is zero in this occasion, thus reducing the loads on the turbine mechanical components and avoiding a run-away condition [44]. The pitch angle saturation and the rate limiter are also added into the pitch controller, in which the pitch angle ranges from 0 to 30 degrees and the pitch rate limit is set to be 10 degree/second. Therefore it prevents the blades from damaging due to frequently operating the blades.

4.6 Energy Storage System

Energy storage System (EMS) is used to help the distribution systems at peak load as the consumption of electricity is high by the customers. Thus energy storage units are used in order to supply the required balanced power between the load and generation units. Thereby providing energy to the grid and other micro units having insufficient energy to manage the load. This problem arises as the demand increases in certain area and that excess requirement is difficult to meet by the distributed resources present in that area. In order to meet these additional requirements, the Energy storage system can be used to boostthe system requirement in given period of time and avoid power outage.

Energy storage system stores the excess power generated during off-peak time and during peak demand, when there is heavy utilization of power, the stored energy in EMS is used to feed the demand. Various technologies is implemented to store this energy in battery system but most commonly flywheels and electrochemical capacitor. Few other technologies used in this sector are compressed air energy storage (CAES) and superconducting magnetic energy storage system (SMES).

4.7 Fuel Cell:

Fuel cell makes use of chemical reaction to generate electricity. It is possible to generate electricity with minimum pollution by making use of Fuel cell as it makes use of hydrogen and oxygen to ultimately generate electricity and a harmless byproduct, water. Fuel cells provide efficient and clean energy using this energy conversion and thus regarded as renewable energy resources. In general, chemical reaction takes place inside the fuel cell and it makes use of two electrodes, an anode and cathode respectively and an

electrolyte between them for the reaction to take place. Hydrogen is the basic fuel for the reaction to take place but it also makes use of oxygen and a catalyst to speed up the reaction [45].

As fuel cells are static in nature because of their quiet operation without noise or vibration and its simple modular construction makes them highly efficient. Thus fuel cell provides a cleaner, much efficient and flexible source of energy. A fuel cell consists of following components: Anode, cathode and an electrolyte between them. The figure below shows the process of fuel cell operation:

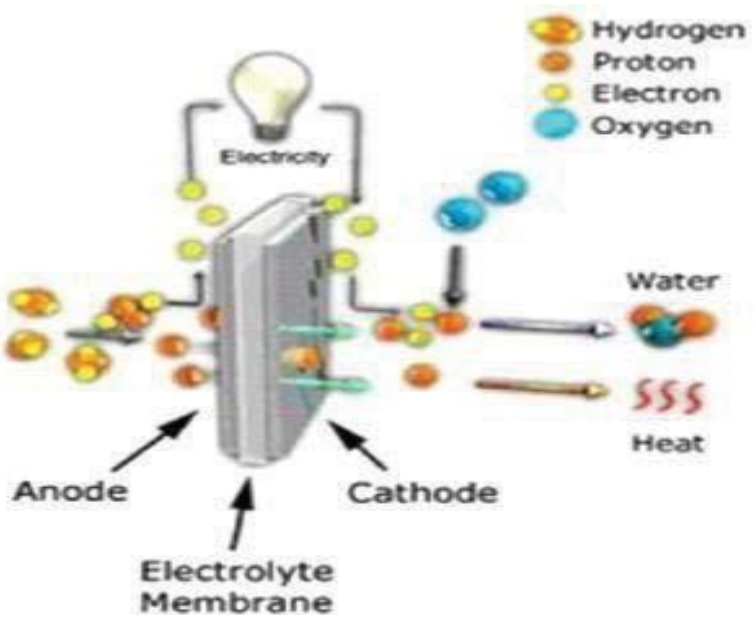

Figure 4.13 Fuel cell operations [46]

The chemical reaction on which this occurs is as follows:

$$H2 = 2H+ + 2e-$$

The hydrogen ions travel through the acidic electrolyte and the electrons travel to the cathode end to complete the circuit. At cathode end, the electrons and hydrogen ions react with oxygen which is supplied to the tank through external pipeline to form water.

$$O2 + 2H+ + 2e- = H2O$$

The total reaction of fuel cell is shown below which gives out water, electric work and heat as output:

$$H2O + O2 = H2O + Wele + Qheat$$

The by-products; heat and water are continuously removed so as to continuously maintain the isothermal operation for generation of electricity. Therefore, water and heat needs to be managed efficiently for effective operation of fuel cells.

Comparison of Fuel cell and Battery with IC engine:

The fuel cell and heat engines make use of hydrogen based fluid as fuel and air as oxidants. But the fuel cell electrochemically converts the fuel and oxidants whereas IC engine uses combustion process for the same. As combustion is a multistep process it firstly, produces thermal energy from chemical energy of the fuel and then is converted to mechanical energy and eventually generators are used to convert it into electrical energy.

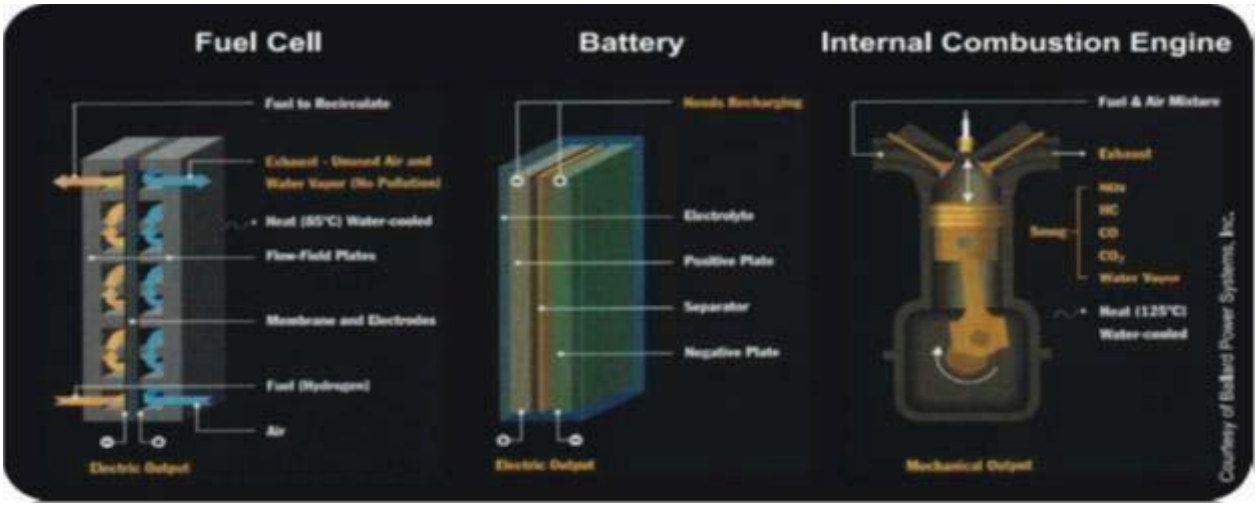

Figure 4.14 Comparison of Fuel cell, Battery and IC engine

Fuel cell and batteries work on same working principle and consist of electrochemical cells i.e. electrolyte between two electrodes. In order to generate electrical energy, both system use oxidation reduction methods to convert the stored chemical energy. But the type of material and its composition significantly differs for both of them. In a battery metal rods are immersed in acidic solutions. The fuel cell consists of 2 electrodes and an electrolyte for conduction and transportation of electrons. In a battery, the energy stored in electrodes is utilized by electrochemical reactions at certain potential difference. Thus, a battery has limited life time and can be used till complete depletion of electrode material doesn't take place.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Overview

The proposed hybrid energy system, shown in Fig. 1 & 2 consists of DFIG based variable speed wind energy conversion, PV array, battery, fuel cell and electrolyzer. WT and PV energy sources are managed with maximum power point tracking (MPPT) algorithms and connected to the common DC bus. Where, in the WT case, the MPPT algorithm is applied at below nominal turbine speed. Beyond the nominal speed, we will be acting on the pitch angle control, whereas the power extraction maximization amounts to regulate the power produced at its rate value. The

Battery is used as a storage device and is connected to the DC bus through DC/DC Buck-Boost bidirectional converter (BBDC). Wind and solar power depend on weather conditions and during night hours solar power is zero. Therefore, under the situation of long term no-wind and solar or low-wind and solar condition, battery alone cannot cater the load demand. Hence, fuel cell (FC) is integrated to make the system more sustainable. In case of high power generation from wind and solar for a long time and the battery reached its upper limit of charge storage, the electrolyzer comes into effect and consumes the surplus power. The hydrogen generated from the electrolyzer can be stored and used as input by FC.

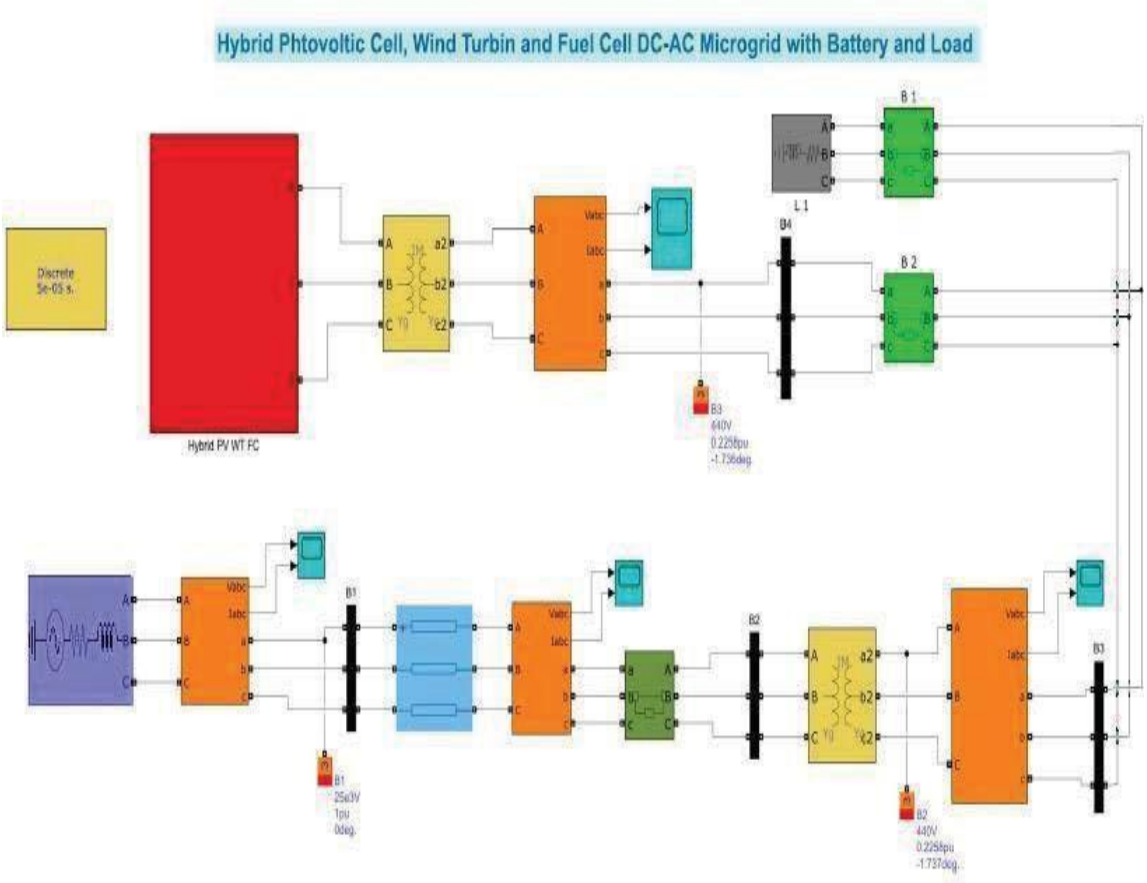

Fig 5.1Hybrid PV/WT and FC system with transmission line and load

5.2 Elements of System

Typically, grid-connected PV system consists of solar panels, DC-DC converter, MPPT controller, inverter and grid connection equipment. It has no energy storage losses since there are no batteries used as it is not a standalone system. The system's components are modeled in Matlab/Simulink software environment. Matlab/Simulink is selected, due to its reusability, extendibility, and flexibility in such systems. It is a dynamic model where the simulation time is 3 s, sampling time is 10^{-5} s, since the time step has to be lower than the propagation time. The model can predict the performance of the system and assess it by comparing the set up to new introduced set ups with added components, solving a set of non-linear equations. A schematic of the Simulink model is shown in Fig.5.1.

5.2.1 Photo voltaic array

Solar cells exhibit non-linear current-voltage characteristics as shown below that depend on solar radiation and temperature.

$$I = I_{ph} - I_o \left(e^{\frac{q(V+IR_s)}{nkT}} - 1 \right) - \frac{V+IR_s}{R_{sh}} \qquad \textbf{(5.1)}$$

Where I_{ph} is the photocurrent, Io is the saturation current of the diode, Rs is the series resistance, R_{sh} is the shunt resistance, n is the diode ideality factor, k is Boltzmann's constant (1.4×10^{-23}), q is the electron charge (1.6×10^{-19}), T is the absolute temperature in Kelvin.

5.2.2 Inveter

All photovoltaic systems interface the utility grid through a boost converter and a voltage source inverter. The DC-DC converters are used to balance the system. Inverters are responsible for converting DC power to AC power. This is done by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output. Three-phase inverters consist of one, two, or three arms of power switching devices. Each arm consists of four switching devices along with their anti parallel diodes and two neutral clamping diodes. The control signal generated by any MPPT method, feed the boost converter switch.

5.2.3 MPPT control

There is a point where the output power from the array (a string of panels) has a maximum value. In order to ensure efficient operation of the solar array the MPP of the array has to be tracked. MPPT, in addition to raising the power delivered from the PV module to the load, is considered as a PV system lifetime booster. There are many control strategies and controller types. These methods can be grouped based on different features.In essence, MPPT methods are categorized into: offline methods which are dependent on solar cell models, online methods which are usually referred to as the model-free method.

The MPPT technique that generates the control signal which feeds the boost converter is assumed to be fractional OCV technique. This technique is under the MPPT offline methods which generally require the knowledge of one or more of the solar panel parameters values; here the open circuit voltage (V_{OC}). These values generate the control signal necessary for driving the solar cell to its MPP. In the tracking operation, this control signal remains constant if ambient conditions can be regarded as fixed and there are no attempts to regulate the output power of the PV system.

The OCV technique is chosen because it is one of the most straightforward off line methods. It uses the almost linear relationship between the open circuit voltage (V_{OC}) and the MPP voltage (V_{MPP}) under changed climatic circumstances as described by the following equation:

VMPP=k* VOC

Where *k* is a constant, depending on the solar cell characteristics.

The constant *k* is derived empirically after measuring several V_{OC} and V_{MPP} for any specific cell under different climatic conditions. Values for the constant *k*, in general, vary between 0.73 to 0.80, here in our specific case, the constant *k* is assumed to be 0.8.

The efficiency was calculated of the technique by the following formula shown in Eq. (5.2), to validate it:

$$\eta = \left(\frac{P_{\max.Tracked}}{P_{\max.}} \right) \times 100 \qquad \textbf{(5.2)}$$

Where ri is the efficiency of the tracking method, $P_{\max.tracked}$ is the MPP tracked and $P_{\max.}$ is the actual MPP of the array derived by the following equation:

Pmax = VMPP *No. of series modules* IMPP* No. of parallel

Where V_{MPP} is the voltage of the solar cell at MPP and I_{MPP} is the current of the solar cell at MPP, bearing in mind that these two parameters vary according to radiation and temperature.

5.2.4 Transformer

To connect the PV system to the national high voltage grid, a transformer is added to the system. Its function is to change the ratio of voltage to current delivered from a voltage source to meet the characteristics of the load, keeping the power constant. Transformers consist of primary coil which receives energy from the AC source (here the inverter), secondary coil which receives energy from the primary winding and delivers it to the load (here the national grid) and the core which makes a path for the magnetic flux.

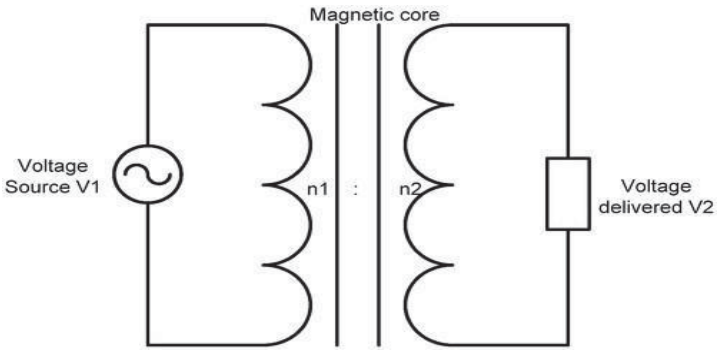

Fig 5.2 Basic Diagram of Transformer

Transformers are either step-up (deliver higher voltage to the load) or step down (deliver lower voltage to the load) according to the ratio of the number of turns of the secondary to the primary.

$$V_2 = \frac{n_2}{n_1} V_1 , I_2 = \frac{n_1}{n_{21}} I_1 , P = V_1 I_1 = V_2 I_2 \qquad \textbf{(5.3)}$$

Where: V_1, I_1 are the voltage and current received from the source to the primary coil; V_2, I_2 are the voltage and current delivered to the load from the secondary coil; n_1,n_2 are the number of turns of the primary and secondary coils. As for the high voltage assumed grid, it consists of a distribution feeder and a transmission system.

5.3 Model formulation and structure

A. Photovoltaic Cell

The PV cell mathematical model is represented here. The typical PV module power characteristic is given in Fig 1. In order to extract the maximum available power from a

PV array, it is necessary to operate the PV array at its maximum power point. The MPPT device is a high-frequency boost dc-dc converter inserted between the PV array and the dc bus, and it takes the dc input from the PV array, convert it to a different dc voltage and current to exactly match the PV array to the dc bus.

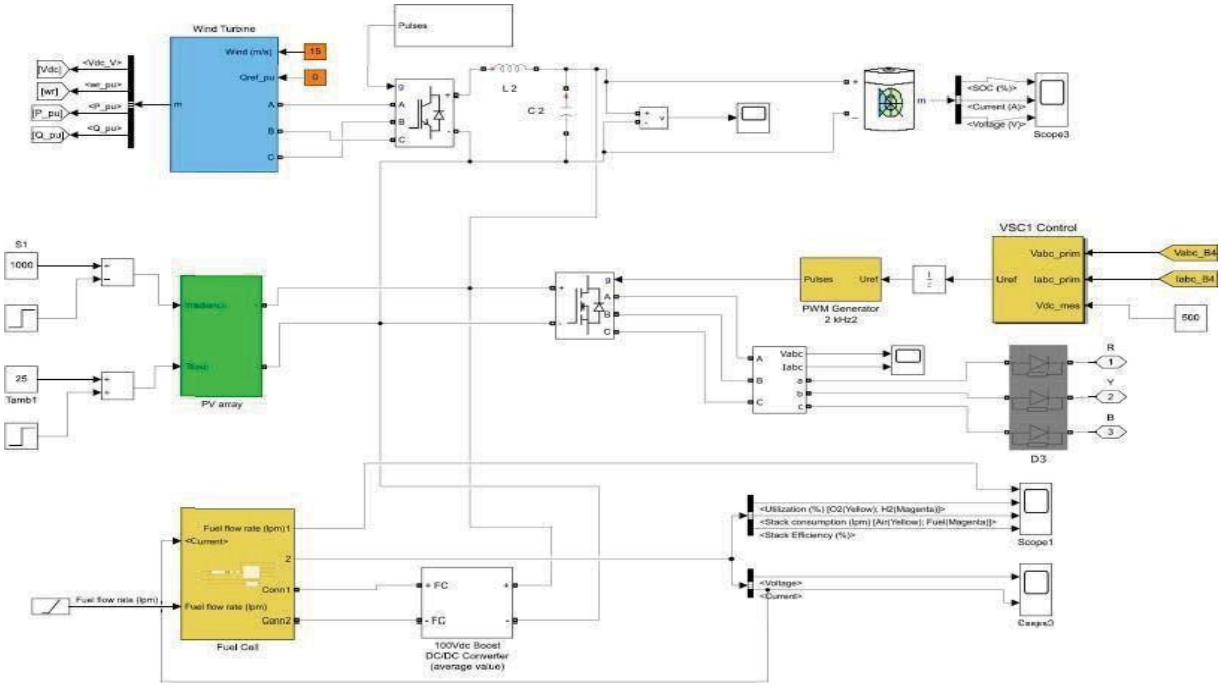

Fig 5.3 PV/WT and FC to DC-DC bus and DC-AC Bus

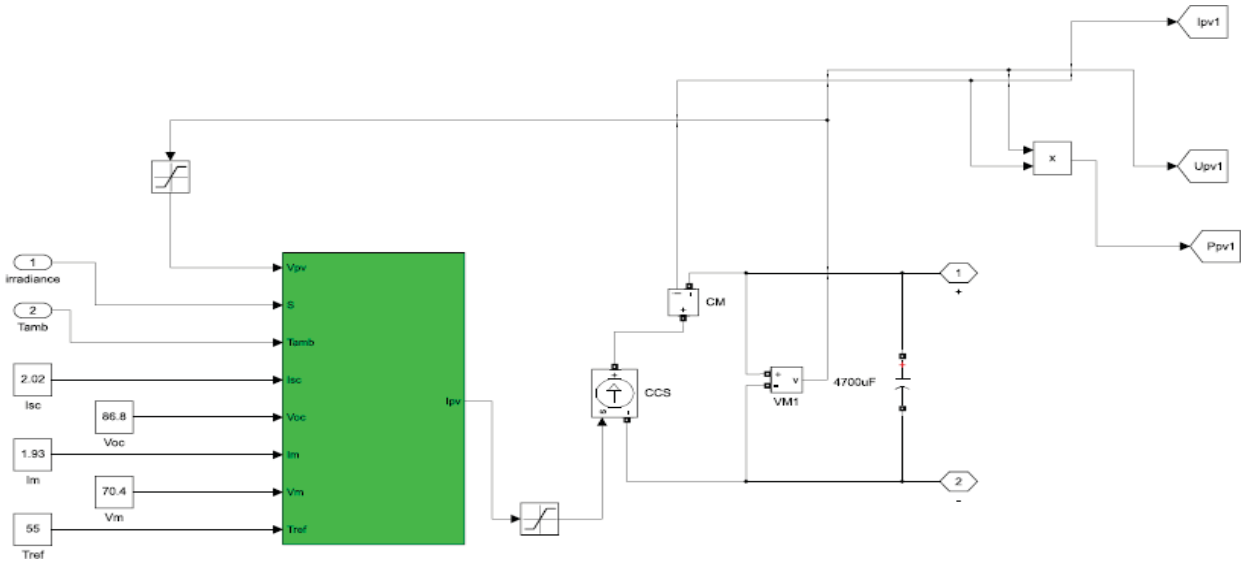

Fig 5.4 Modeling of PV with irradiance and temperature

Fig.5.4 shows that the output power is directly proportional to the irradiance. As such, a smaller irradiance will result in reduced power output from the PV module. However, it is also observed that only the output current is affected by the irradiance. This is expected, because the generated current is proportional to the flux of photons. According to Vmpp they result 4 arrays are connected in parallel; each array consists of 27 modules connected in series. Each of them delivers 108 W peaks.

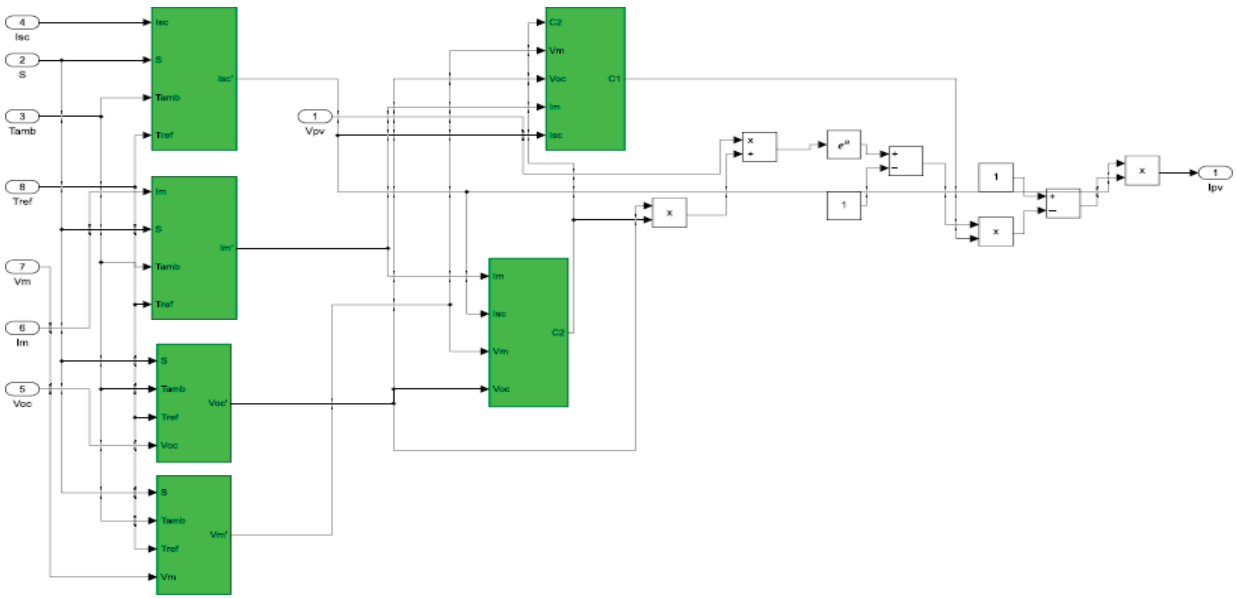

Fig 5.5 Calculation of Photo Current in PV model

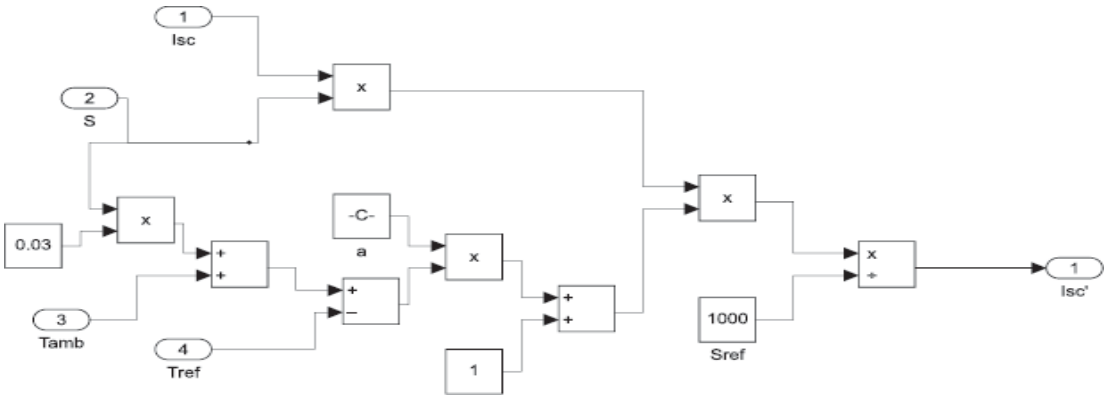

Fig 5.6 Calculation of Short circuit Current in PV model

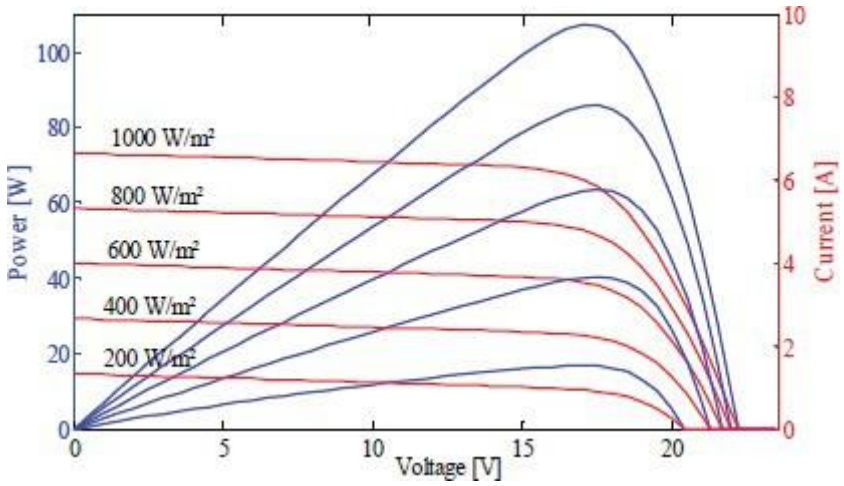

Fig 5.7 Typical PV module unit I-V and P-V characteristic showing the effects of irradiance

B. Wind Energy Conversion

The aerodynamic power at the rotor of the turbine is given by the following equation:

$$P_{wind} = \frac{1}{2}\rho A v^3 C_p(\lambda,\theta) \qquad \textbf{(5.4)}$$

Where p is the air density in kilogram per cubic meter, A is the area swept by the rotor blades in square meter, and v is the wind velocity in meters per second. Cp is called the power coefficient or the rotor efficiency and is a function of tip speed ratio (A) and pitch angle (�).

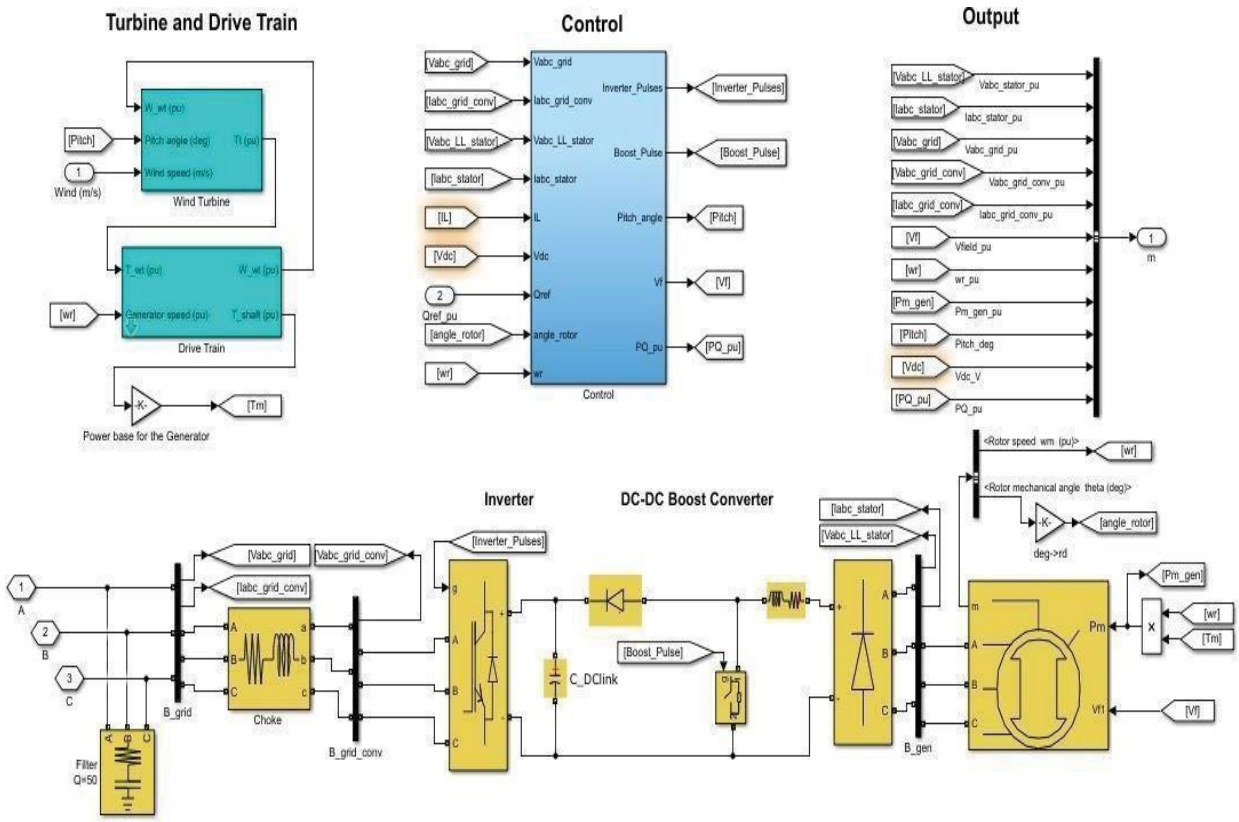

Fig 5.8 Modeling of WT with converters

C. Fuel Cell

The FC is a device for directly converting the chemical energy of a fuel, into electrical energy. The output voltage of a single cell given in [10-12] can be defined as in (5.5):

$$E_{cell} = E_{Nernst} - E_{Act} - E_{Con} - E_{Ohm} \qquad \textbf{(5.5)}$$

Where E_{Nernst} is the reversible voltage, E_{Act} is the activation voltage drop, E_{Con} is the concentration voltage drop, and E_{Ohm} is the Ohmic voltage drop.

The terminal voltage of PEM fuel cell stacks is defined as in (5.6).

$$V_{FC} = N_s E_{Cell} \qquad \textbf{(5.6)}$$

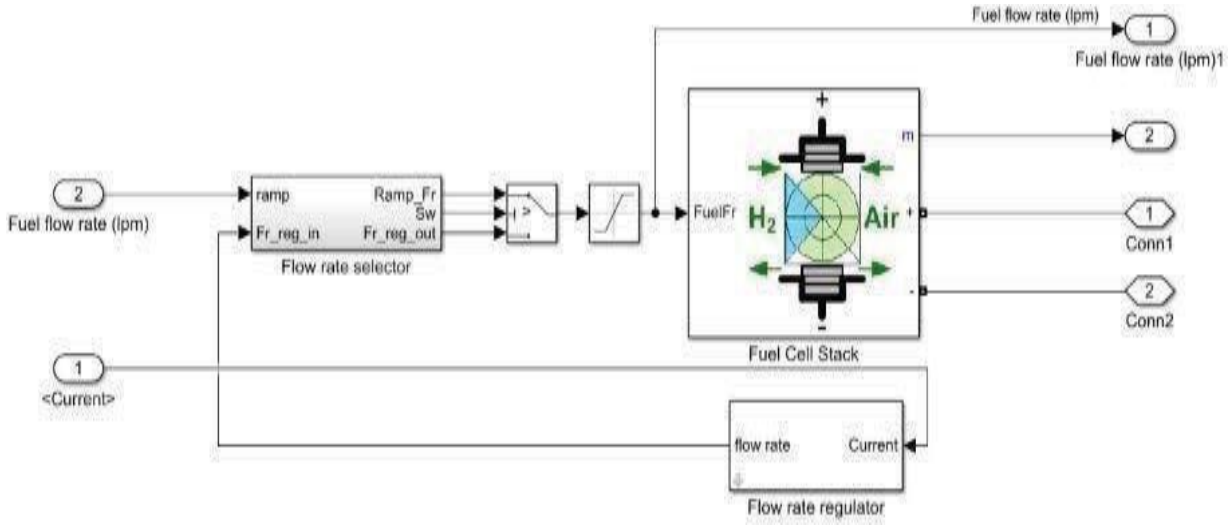

Fig 5.9 Modeling of FC with converters

Fig. 5.9 shows voltage and power versus current polarization curves of a PEM FC. It is shown that the activation voltage drop dominates at low current, the Ohmic drop voltage dominates at mid-range current, and the concentration drop voltage dominates at high current. The voltage deviates further as the current is increased, illustrating the effects of drop voltages. In concentration voltage drop region, the FC output power occurs near the FC rated power.

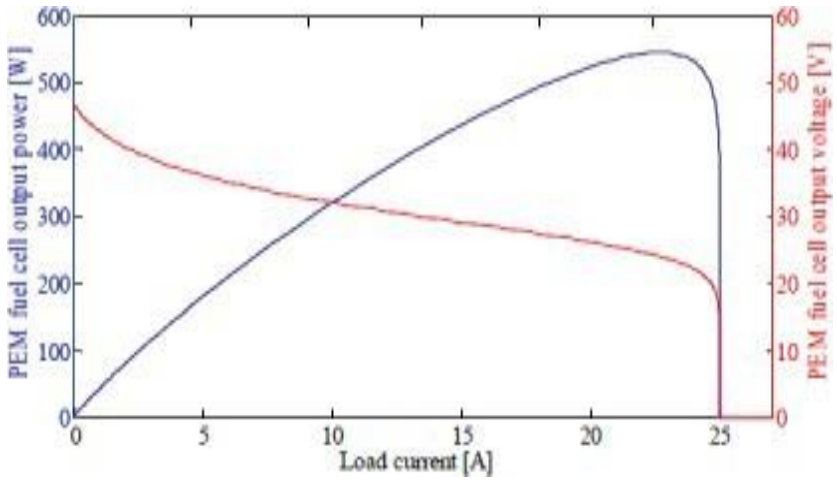

Fig 5.10 Power and voltage versus current polarization curves of PEM FC

The FC controller through which the boost converter switch is controlled. Controllers associated with the battery and FC are developed in such a fashion that when there is a

sudden required power change, the battery provides the power instantaneously and as FC power goes on increasing, battery power should go on decreasing. In order to make the proper coordination between battery and FC, boost converter controller associated with fuel cell is developed based on and assuming battery current is ideally zero. Moreover, when the battery state of charge (SOC) is below 20 %, the fuel cell should give power to the battery. The PEM fuel cell is composed of 2x6 stacks with the power rating of 10 kW.

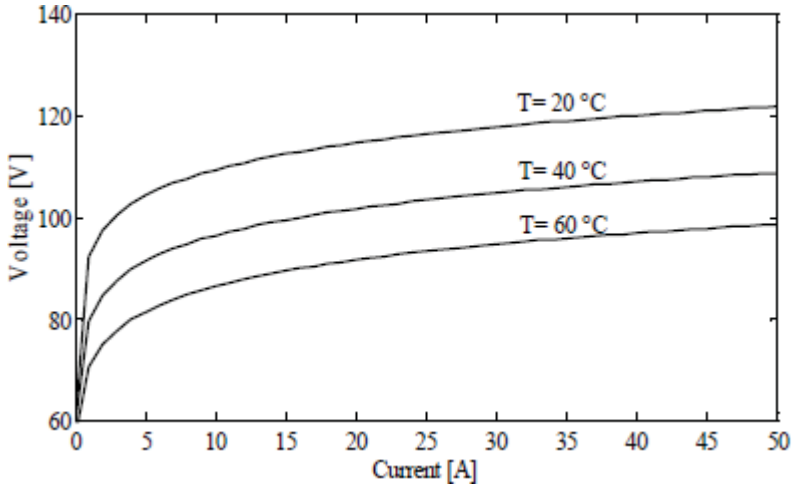

Fig 5.11 Typical U-I characteristic of an electrolyzer under different Temperatures

D. Electrolyzer

The description of the water electrolyzer is developed here. The U-I characteristics of the electrolyzer model used in this study at different cell temperatures. At a given current, the higher the operating temperature, the lower is the terminal voltage needed. The excess energy produced is first pushed into the battery until it reaches its upper limit of charge carrying capacity and then the excess power is fed to the electrolyzer and is regulated via the buck DC/DC converter. The decision about switching on the control action is carried out by comparing the upper limit of the state of charge (SOC) of the battery and the present status of SOC. When the SOC becomes higher than its limit, 80 %, the controller will increase the duty cycle as a function of over voltage in the dc bus voltage.

5.4 SIMULATION RESULT AND DISCUSSION

Using the component models, a simulation system test for the proposed WTDFIGs/PV/FC-Electrolyzer energy system has been developed using MATLAB/Simulink, the WT-DFIGs and the PV parameters are given. In order to verify

the system performance under different situations, simulation studies have been carried out using variable load demand data and random weather data (wind speed, solar irradiance, and air temperature).

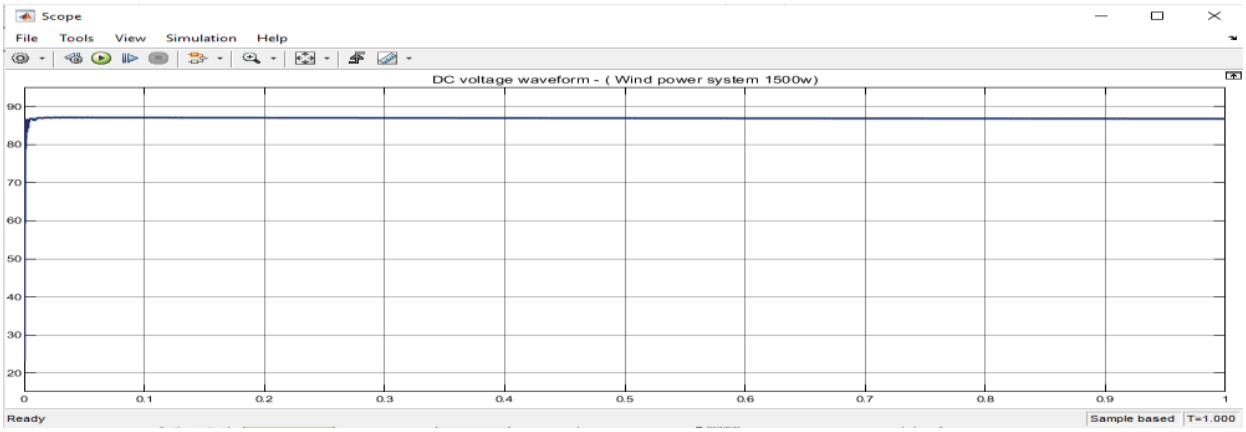

Fig 5.12 DC-DC Micro grid voltage

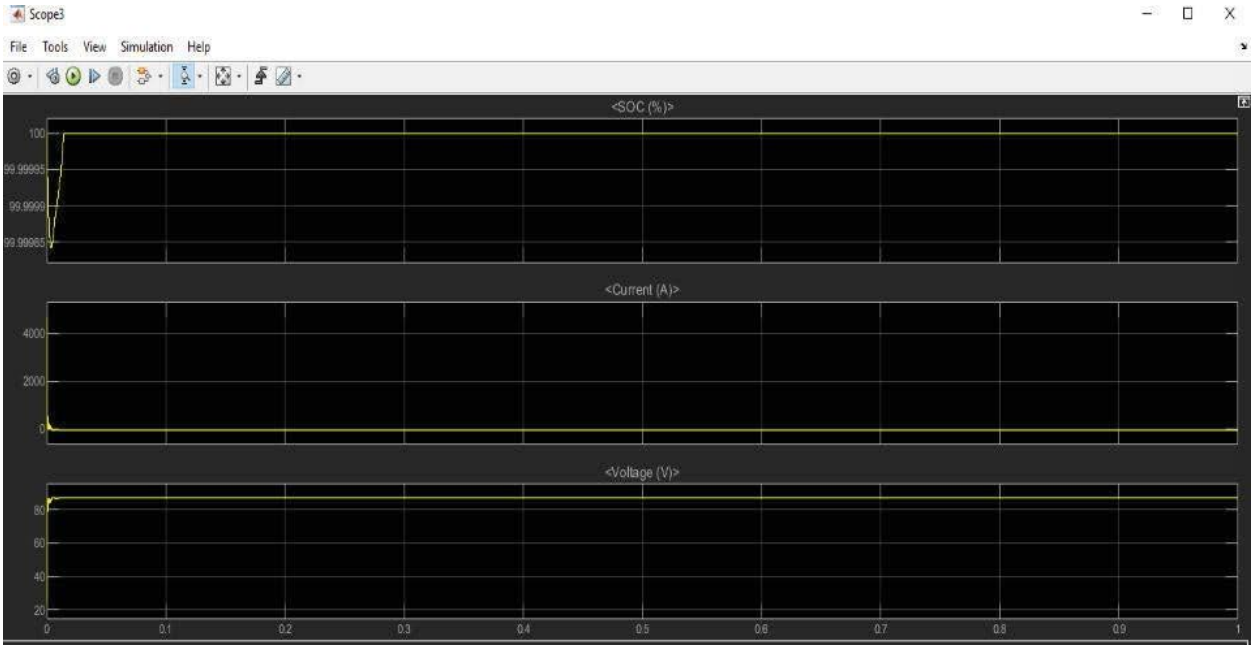

Fig 5.13 SOC, Current and Voltage of Battery

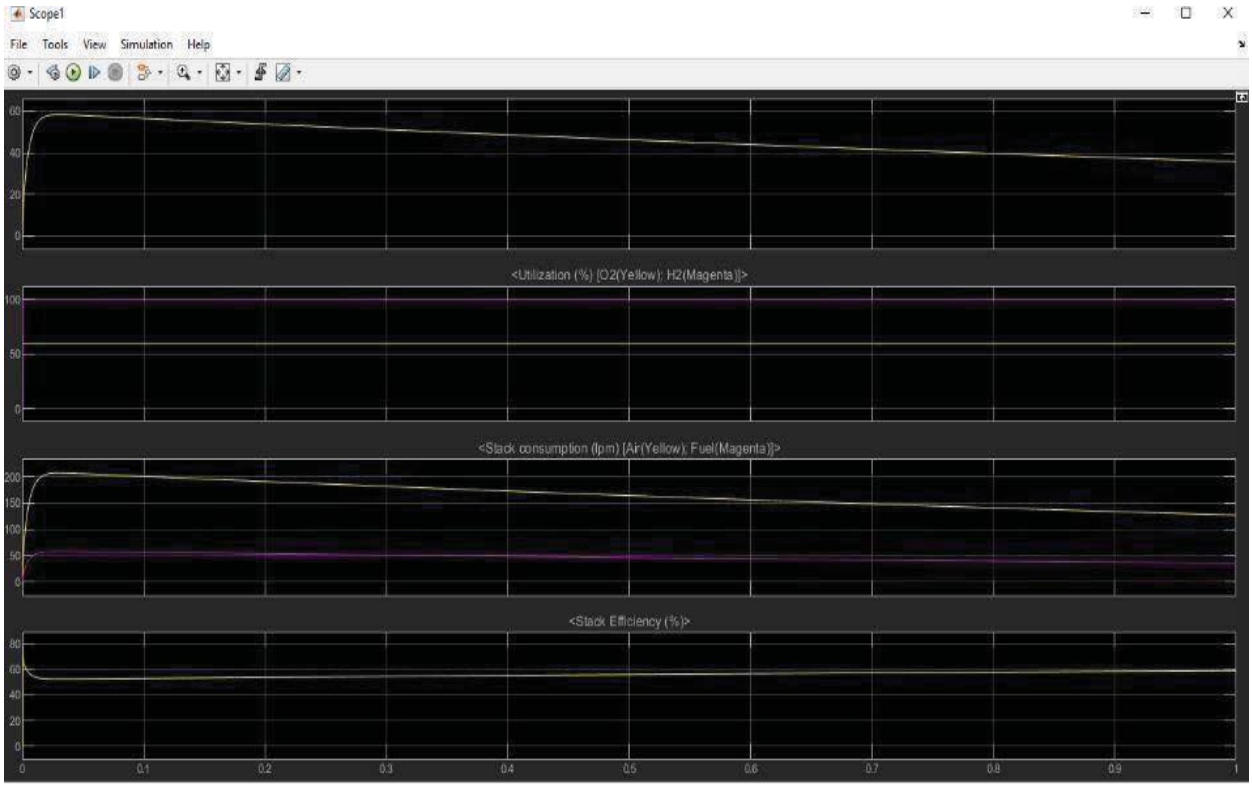

Fig 5.14 Characteristic of FC

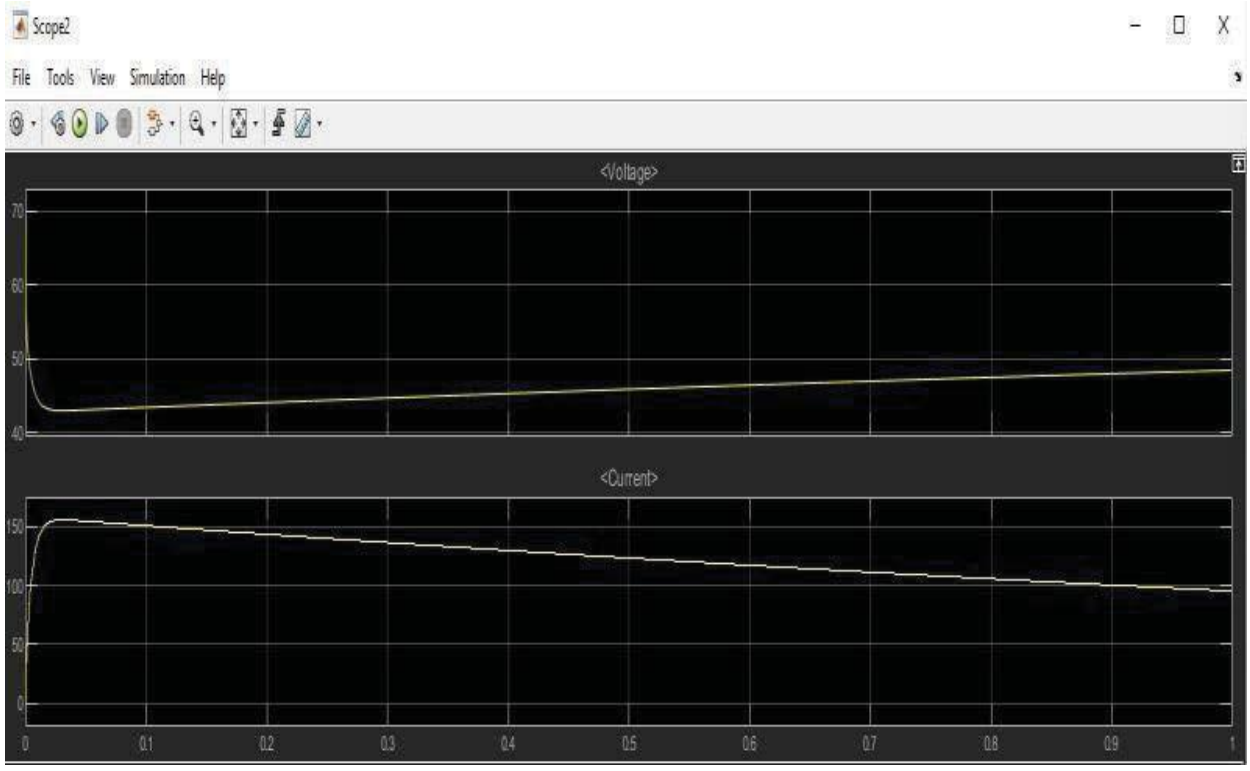

Fig 5.15 Voltage and Current of FC

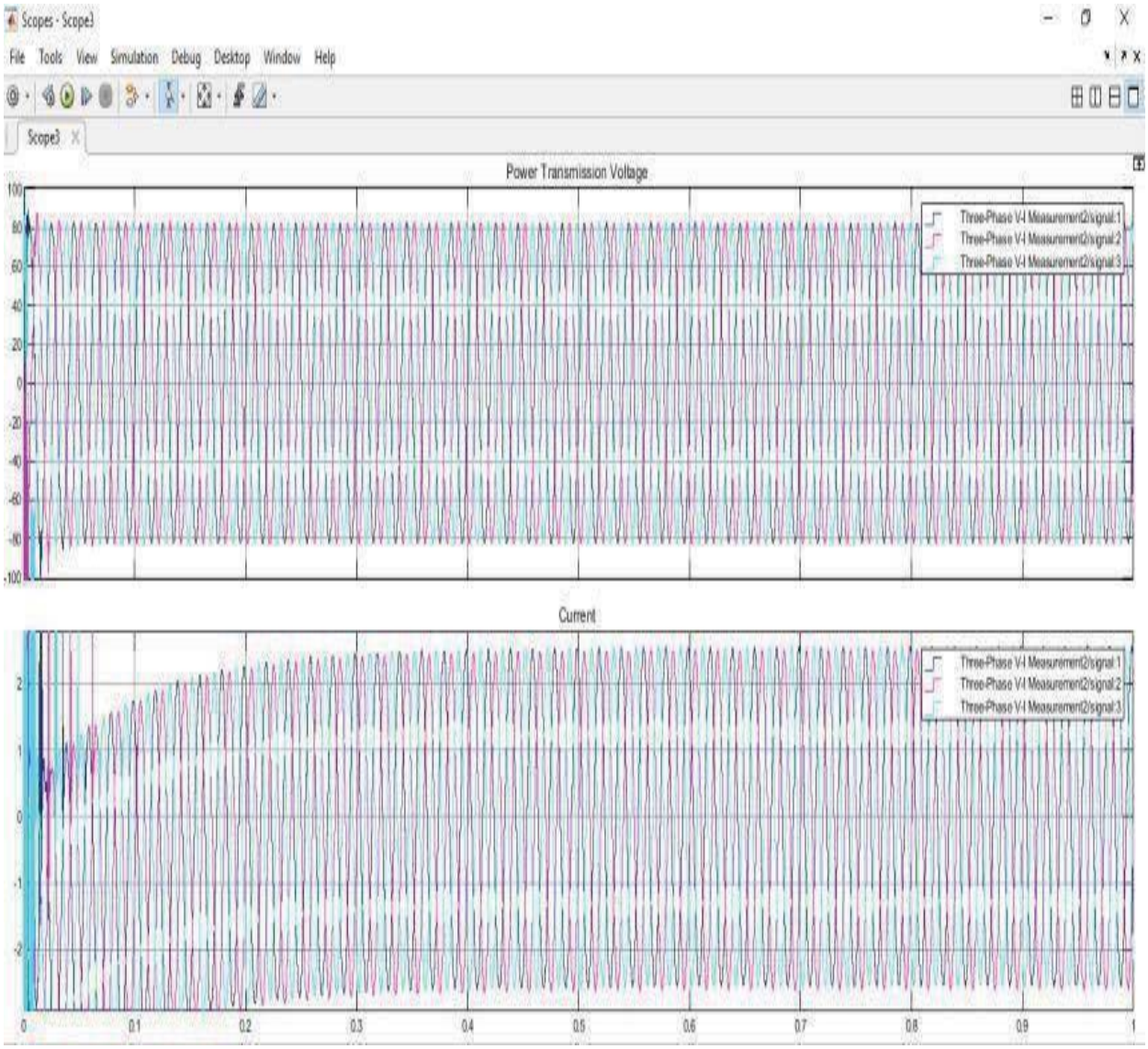

Fig 5.16 Voltage and Current of DC-AC Converter

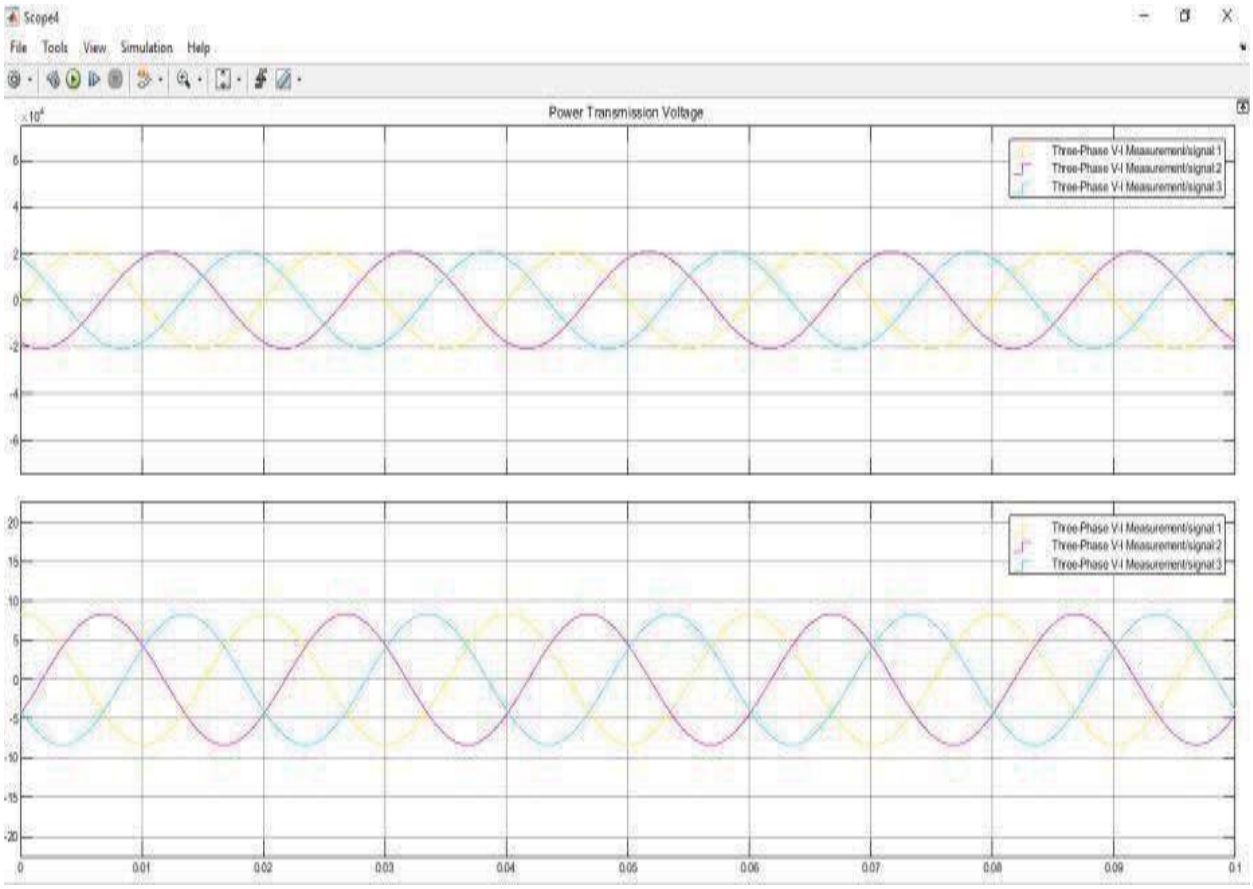

Fig 5.17 Voltage and Current of Load

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

This dissertation is on modeling and control of a hybrid wind/PV/FC alternative energy system. The main part of the dissertation focuses on the modeling of different energy systems and the corresponding control scheme development.

DG system modeling and control are two other aspects of the research presented in the dissertation. A hybrid alternative energy system has great potential for use as a DG source.

The conclusions of the research work reported in this dissertation are summarized as below.

(1) Environmentally friendly and sustainable alternative energy systems will play more important roles in the future electricity supply.

(2) Dynamic models have been developed for the following: fuel cells (PEMFCs and SOFCs), variable speed wind energy conversion systems, photovoltaic power generation systems, electrolyzers, power electronic interfacing devices, battery banks and accessories including gas compressor, high-pressure hydrogen storage tank, and gas pressure regulator. These dynamic models are suitable for both detailed fast transient and large time scale performance evaluation studies. They can be used to expedite research processes in related alternative energy areas, such as system control and performance optimization studies.

(3) A hybrid wind/PV/FC DG system is proposed in this dissertation. Wind and PV are the primary power sources of the system, and the combination of FC and electrolyzer is used as a backup and long term storage unit. The different energy sources in the system are integrated through an AC link bus. The system can be used as test-bed system for other related studies on hybrid alternative energy systems.

(4) Based on the dynamic component models, a simulation model for the proposed hybrid wind/PV/FC energy system has been developed successfully using

MATLAB/Simulink. The overall power management strategy for coordinating the power flows among the different energy sources is presented in the dissertation. Simulation studies have been carried out to verify the system performance under different scenarios using practical load profile.

6.2 Future Scope

The next step in research is to consider Micro grid as a system. It is essential to know more about how the sources interact with each other. More specifically their relationship to each other needs to be defined. If all goes as anticipated and the Micro grid system is developed, the control of the system will likely be imbedded within the electronics. It is possible to use specialized controllers to get a more stable response and to use each power source more efficiently. This should certainly be researched and considered once the power sources interaction and relationship with each other and the mains have been defined. Other aspects that could be developed further are the individual sources within the Micro grid. This could be done at two levels. The first is the consideration of other variables for each source.

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LIST OF PUBLICATIONS

1. Seema Kaushal and Urmila S Soni, "Study and Design of AC and Hybrid ACDC Micro grid: a Review" International Journal of Advances in Engineering and Management (IJAEM) Volume 3, Issue 11 Nov 2021, pp: 715-723.
2. Seema Kaushal and Urmila S Soni, "Design and Analysis of Hybrid AC-DC Micro Grid" International Journal of Advanced Research in Electrical, Electronicsand Instrumentation Engineering (IJAREEIE), Volume 10, Issue 11, November 2021.

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Design and Analysis of Hybrid AC-DC Micro Grid

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ABSTRACT: This paper highlights the modeling and the simulation of a micro-grid renewable power system. It comprises a wind turbine (WT) doubly fed induction generators (DFIG), photovoltaic generator (PV), a proton exchange membrane (PEM) Fuel Cell (FC) generator, a water Electrolyzer, a Hydrogen tank, and a battery bank (BBs). The system configuration and the characteristics of the main components in the proposed system are given; and the overall control and power management strategy for this latter are presented. In addition, the dynamic modelsof a boostDC-DC converter and a bidirectional DC-DC (Buck-Boost) converter are considered. A battery bank(BB) is used for short-term energy storage and an electrolyzer is used for long-term energy storage. The excess power from the WT-DFIGs and PV generators is then used for charging BB and for water electrolyzer to produce hydrogen. The (FC)and the (BB) work as a backup generator to supply the demand required power, when the WT- DFIGs and the PV energy are deficient. All the work is undertaken under MATLAB/Simulink environment.

KEYWORDS: Doubly fed induction generator, wind and solar energy, hybrid micro-grid, hydrogen production, Hybrid energy storage system

I.INTRODUCTION

In the last years, the renewable energy sources (RESs) based on micro-grid system applications have attracted more interest. The RESs are non-polluting, free in their availability and continuous. This fact makes this kind of energy attractive for micro-grid applications [1]. Many AESs including wind turbine (WT), photovoltaic panels (PV) and micro-turbines are reported in the literature for hybrid power sources system based on micro-grid applications [2]. As known, the drawback of these structures is the seasonal and daily climatic variations (solar radiation, wind speed, temperature) and geographical conditions as well as the profiles of the required power. This requires adopting other measures as solutions. However, Energy Storage Systems (ESSs) are necessary to mitigate the effects of wind or solar fluctuations and to maintain the power and energy balance as well as to improve the power quality. Hence, they must have a high-power density in order to face fast power variations, and at the same time they must have a high energy density to give autonomy to the micro-grid. For these reasons, it is necessary to associate more than onestorage technology creating a Hybrid Energy Storage Systems (HESSs) [3, 4].

The ESS as BBs is very important for an efficient and economic utilization of these hybrid systems [2]. However, the charge and discharge cycles decrease the life time of batteries [5, 6]. To improve the energy supply reliability of WT and PV hybrid system, a third energy source is needed. The fuel cell (FC) can be combined with an electrolyzer system to ensure the need for any backups the supply power system [7]. The energy management strategies of a micro-grid combined WT, PV and FC containing electrolyzer and battery are the most efficient procedures to produce very high energy quality. In this case, the micro-grid can be associated with distributed generation and decentralized management and that are normally connected to the grid. In addition, the micro-grid based renewable energy can be reduced the transmission losses [8].

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Due to the increasing of DC loads in residential, electric vehicles, industrial and commercial buildings the power system loads may be DC dominated in the near future [8]. If these latter are supplied by means of AC grid, then it requires embedded AC/DC converters and DC/DC converters. The multiple reverse conversions associated with an individual AC or DC grid leads to additional costs and losses. Hence, reduces the overall efficiency of the system. A hybrid AC/DC micro- grid normally associated with individual AC grids or DC grids can overcome the fact that AC loads must be connected to AC grid [7, 9, 10], whereas DC loads are connected to DC grid [5, 6, 8, 10-13], and the AC and DC grids are connected through a bidirectional converter[14].

Several studies and a various configurations of micro-grid applications based on the hybrid energy generations have been proposed [7, 9-12, 14]. However, a little attention has been reserved to the integration of a DFIG on the micro-grid system.

In [14], a hybrid micro-grid consists a WT-DFIG and a FC is proposed, to reduce the process of multiple AC-DC- AC and DC-AC-DC conversions which are commonly seen in an individual AC grid or DC grid. The drawback of this paper is that there is no power management and no battery to support the FC operations. In addition to linear vector control handicap, regarding to the robustness, the advantages provided by DFIG were not reported particularly its operations modes, such as Sub, Super and synchronous modes, which is the case of reference [7], as well as the impact of the over-speeds area (pitch angle control) was not discussed. In the [9], the reactive power required is provided by a synchronous compensator, while the active power is provided by a wind turbine generator. The lacks of this topology is that the cost and the complexity of control have been increased.

The main contribution of this paper is that the proposed micro-grid based on WT-DFIG/PV hybrid power sources system is designed in a new topology. The advantage of this topology is an easier accessibility of AC and DC grid. However, the AC/DC and DC/DC converters required for supplying the DC loads are not needed. This configuration of the micro-grid permits an achieving of optimal and efficient control of the different sources, ensuring better power quality for AC and DC grid, regulating the voltage level and the frequency of AC grid, ensuring continuity of the service and supplying the local reactive power compensation. In addition, a micro-grid based on a multiple source topology can increase the flexibility of power management for the micro-grid into the grid and vice versa. Finally, the simulation of applied management algorithm of the whole system in very severe situations such as: change in power demand, random variations and sudden meteorological conditions, are presented and the results are discussed.
Thus, before presenting the obtained results and their comments, we will describe the proposed system and the control techniques used.

II. DESCRIPTION OF THE PROPOSED MICRO-GRID

The proposed hybrid energy system, shown in Fig. 1 & 2 consists of a DFIG based variable speed wind energy conversion, PV array, battery, fuel cell and electrolyzer. WT and PV energy sources are managed with maximum power point tracking (MPPT) algorithms and connected to the common DC bus. Where, in the WT case, the MPPT algorithm is applied at below nominal turbine speed. Beyond the nominal speed, we will be acting on the pitch angle control, whereas the power extraction maximization amounts to regulate the power produced at its rate value. The Battery is used as a storage device and is connected to the DC bus through DC/DC Buck-Boost bidirectional converter (BBDC). Wind and solar power depend on weather conditions and during night hours solar power is zero. Therefore, under the situation of long term no-wind and solar or low-wind and solar condition, battery alone cannot cater the load demand. Hence, fuel cell (FC) is integrated to make the system more sustainable. In case of high- power generation from wind and solar for a long time and the battery reached its upper limit of charge storage, the electrolyzer comes into effect and consumes the surplus power. The hydrogen generated from the electrolyzer can bestored and used as input by FC.

A. Photovoltaic Cell

The PV cell mathematical model is represented in [11, 12]. The typical PV module power characteristic is given in

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Fig 1. In order to extract the maximum available power from a PV array, it is necessary to operate the PV array at its maximum power point. The MPPT device is a high-frequency boost dc-dc converter inserted between the PV array and the dc bus, and it takes the dc input from the PV array, convert it to a different dc voltage and current to exactly match the PV array to the dc bus.

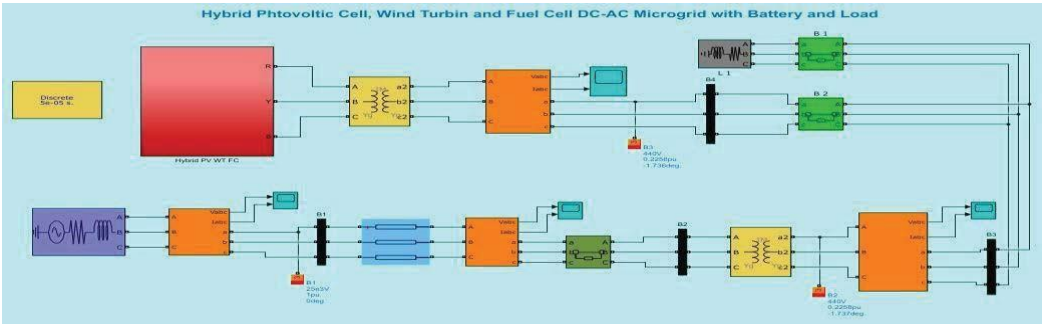

Fig 1. Hybrid PV/WT and FC system with transmission line and load

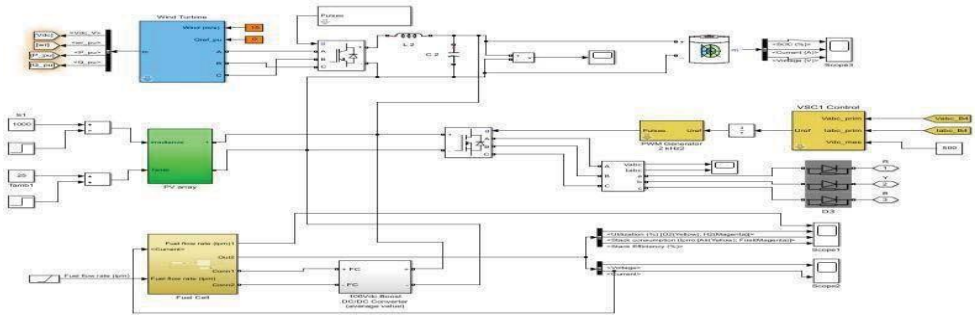

Fig 2. PV/WT and FC to DC-DC bus and DC-AC Bus

III. SYSTEM MODELING AND CONTROL

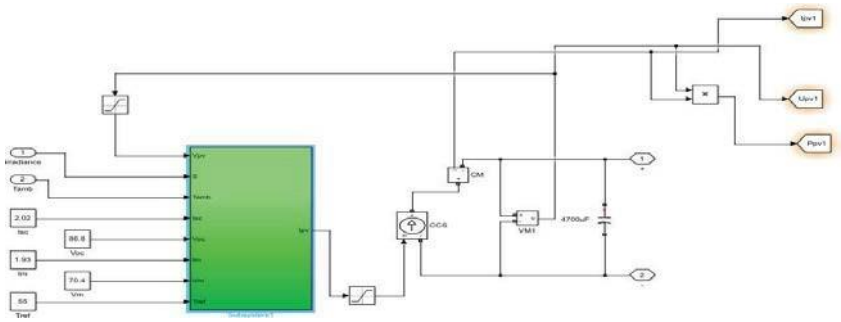

Fig 3. Modeling of PV with irradiance and temperature

Fig.3 shows that the output power is directly proportional to the irradiance. As such, a smaller irradiance will result in reduced power output from the PV module. However, it is also observed that only the output current is affected by the irradiance. This is expected, because the generated current is proportional to the flux of photons. According to V_{mpp} they result 4 arrays are connected in parallel; each array consists of 27 modules connected in series. Each of themdelivers 108 W peaks.

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B. Wind Energy Conversion

The aerodynamic power at the rotor of the turbine is given by the following equation:

$$P_{wind} = \frac{1}{2}\rho A v^3 C_p(\lambda,\theta) \qquad (1)$$

Where p is the air density in kilogram per cubic meter, A is the area swept by the rotor blades in square meter, and v is the wind velocity in meters per second. Cp is called the power coefficient or the rotor efficiency and is a function of tip speed ratio (A) and pitch angle (θ) [15].

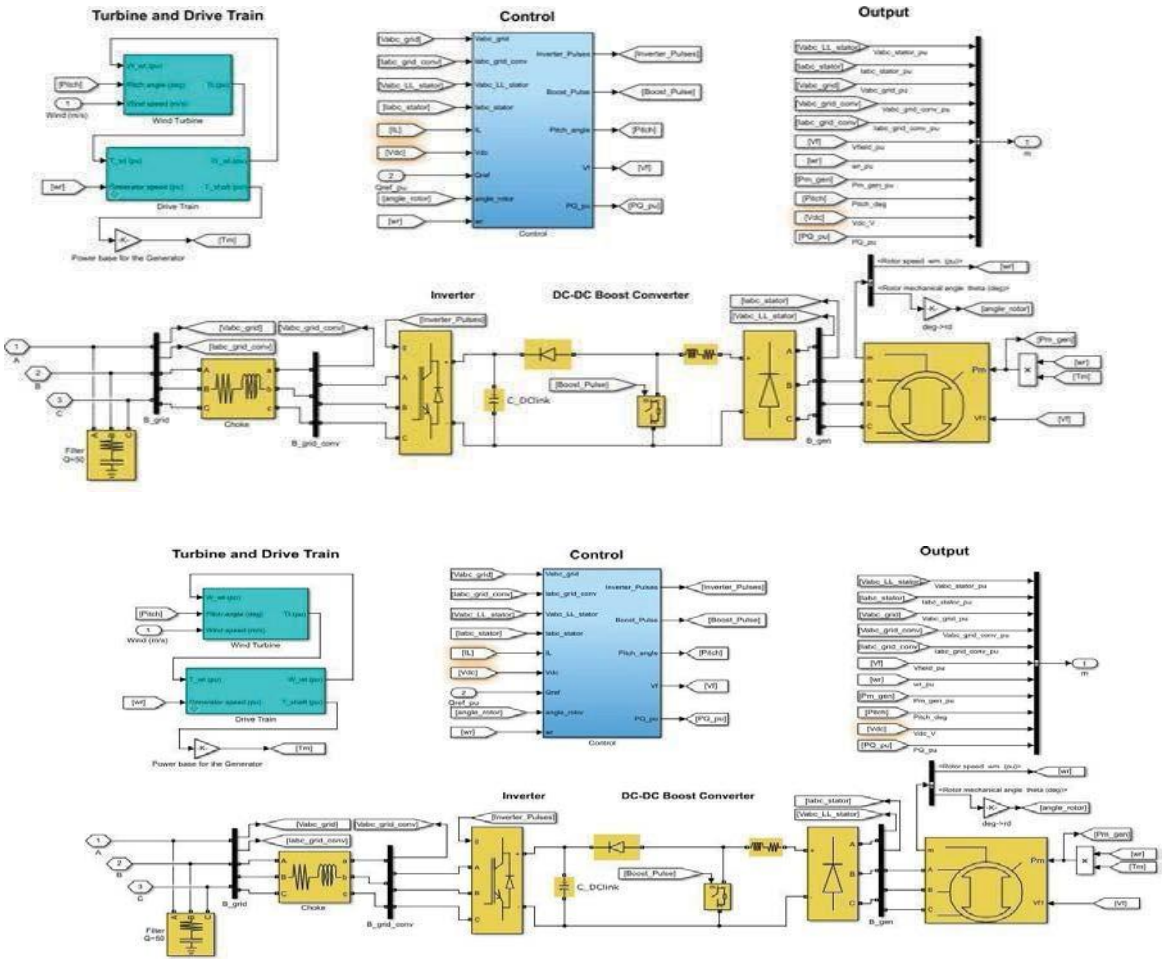

Fig 4. Modeling of WT with converters

The proposed WT-DFIGs control strategy is illustrated in Fig. 1. This latter is based on DTC combined with a fuzzy logic control technique, called a direct torque reactive power control (DTRPC). So, the reactive and active powers are controlled respectively with the rotor flux and electromagnetic torque. These latter are considered to be the outputs of the fuzzy controllers established for regulating the reactive power and the mechanical speed of DFIG.

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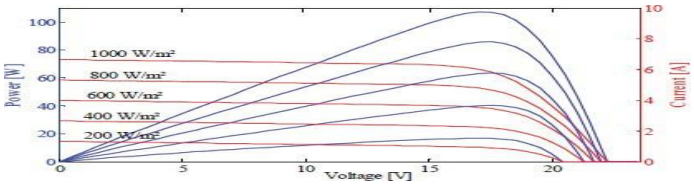

Fig 5. Typical PV module unit I-V and P-V characteristic showing the effects of irradiance.

C. Fuel Cell

The FC is a device for directly converting the chemical energy of a fuel, into electrical energy. The output voltage of a single cell given in [10-12] can be defined as in (2):

$$E_{cell} = E_{Nernst} - E_{Act} - E_{Con} - E_{Ohm} \quad (2)$$

Where E_{Nernst} is the reversible voltage, E_{Act} is the activation voltage drop, E_{Con} is the concentration voltage drop, and E_{Ohm} is the Ohmic voltage drop. The terminal voltage of PEM fuel cell stacks is defined as in (3).

$$V_{FC} = N_s E_{Cell} \quad (3)$$

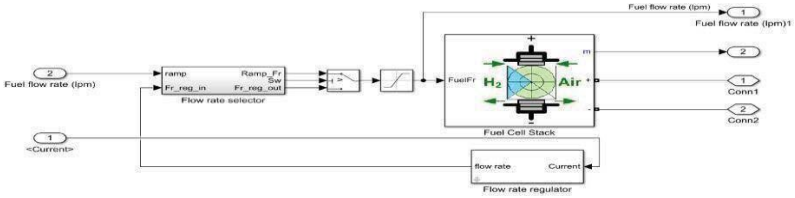

Fig 6. Modeling of FC

Fig. 7 shows voltage and power versus current polarization curves of a PEM FC. It is shown that the activation voltage drop dominates at low current, the Ohmic drop voltage dominates at mid-range current, and the concentration drop voltage dominates at high current. The voltage deviates further as the current is increased, illustrating the effects of drop voltages. In concentration voltage drop region, the FC output power occurs near the FC rated power.

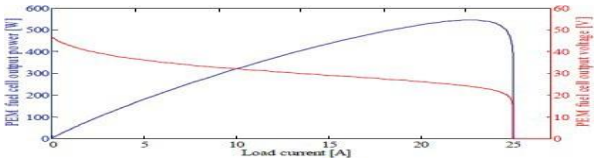

Fig 7. Power and voltage versus current polarization curves of PEM FC

The FC controller through which the boost converter switch is controlled. Controllers associated with the battery and FC are developed in such a fashion that when there is a sudden required power change, the battery provides the power instantaneously and as FC power goes on increasing, battery power should go on decreasing. In order to makethe proper coordination between battery and FC, boost converter controller associated with fuel cell is developed based on and assuming battery current is ideally zero. Moreover, when the battery state of charge (SOC) is below 20
%, the fuel cell should give power to the battery.
The PEM fuel cell is composed of 2x6 stacks with the power rating of 10 kW.

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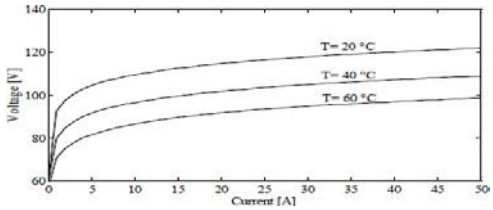

Fig 8. Typical U-I characteristic of an electrolyzer under different Temperatures

D. Electrolyzer

The description of the water electrolyzer is developed in [11, 12]. The U-I characteristics of the electrolyzer model used in this study at different cell temperatures. At a given current, the higher the operating temperature, the lower is the terminal voltage needed. The excess energy produced is first pushed into the battery until it reaches its upper limit of charge carrying capacity and then the excess power is fed to the electrolyzer and is regulated via the buck DC/DC converter. The decision about switching on the control action is carried out by comparing the upper limit of the state of charge (SOC) of the battery and the present status of SOC. When the SOC becomes higher than its limit, 80 %, the controller will increase the duty cycle as a function of over voltage in the dc bus voltage.

IV. SIMULATION RESULT AND DISCUSSION

Using the component models, a simulation system test for the proposed WTDFIGs/PV/FC-Electrolyzer energy system has been developed using MATLAB/Simulink, the WT-DFIGs and the PV parameters are given in [1, 15], but those of the Electrolyzer, BB and FC are given in [11, 13]. In order to verify the system performance under different situations, simulation studies have been carried out using variable load demand data and random weather data (wind speed, solar irradiance, and air temperature).

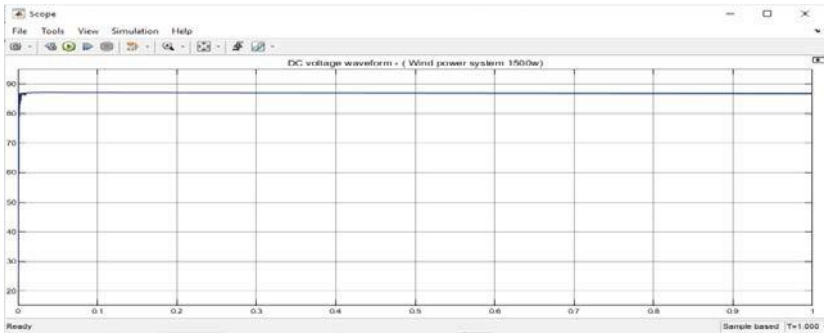

Fig 9. DC-DC Micro grid voltage

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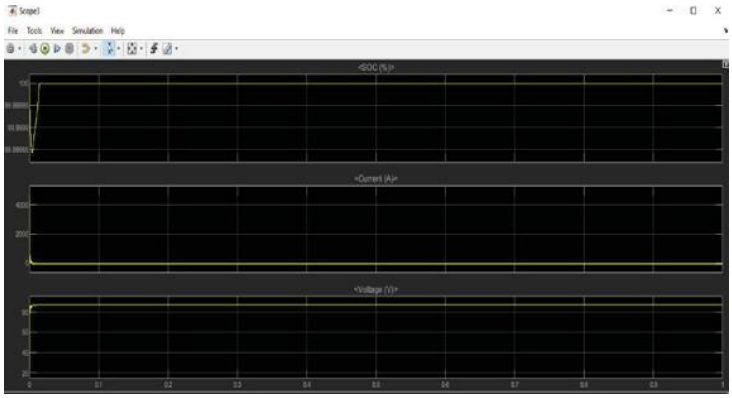

Fig10. SOC, Current and Voltage of Battery

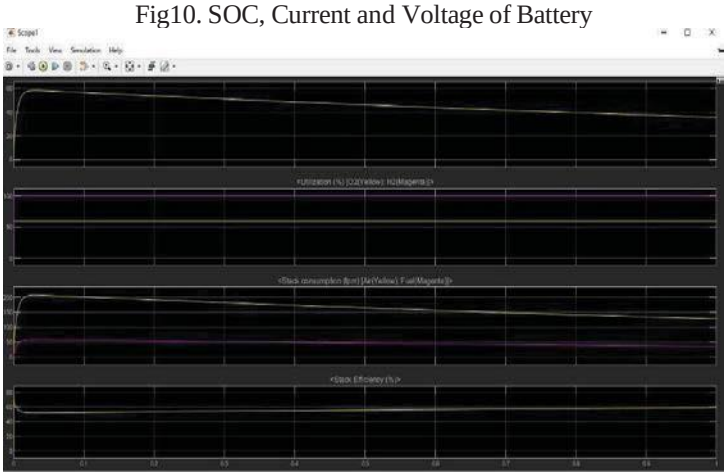

Fig11. Characteristic of FC

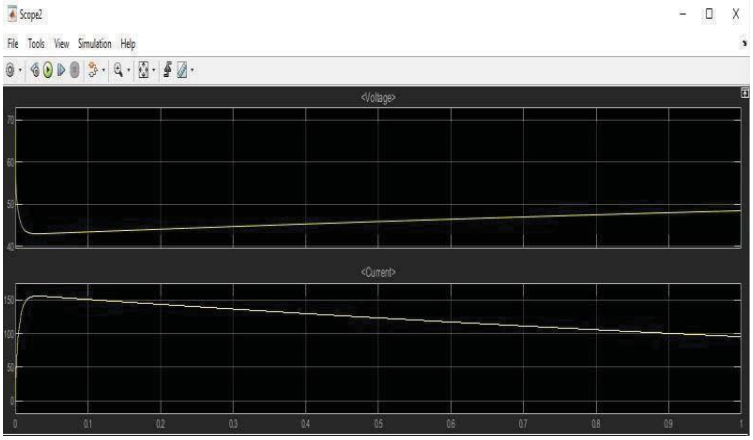

Fig 12. Voltage and Current of FC

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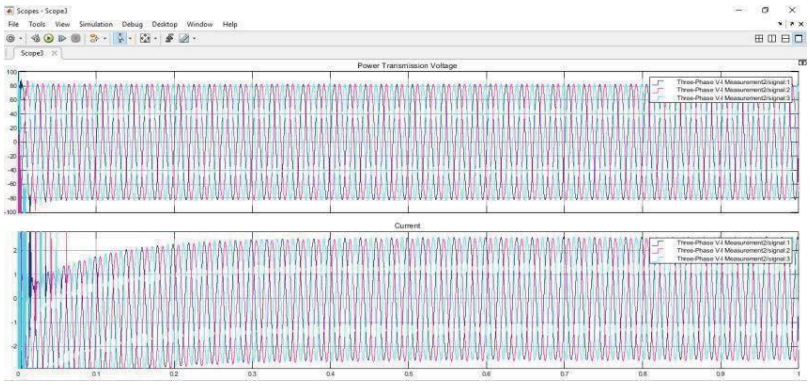

Fig 13. Voltage and Current of DC-AC Converter

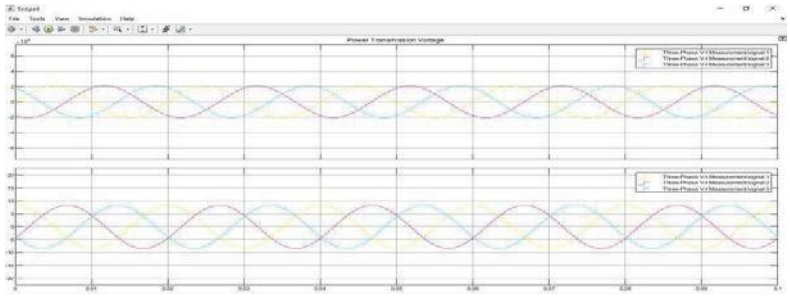

Fig14. Voltage and Current of Load

V. CONCLUSIONS

In this paper, a Hybrid micro-grid system associated to generating system using WT-DFIGs/PV/FC combined with a hybrid energy storage system is proposed. The system configuration and the characteristics of the main components in the system are given, and the overall control and power management strategy for the proposed hybrid energy system is presented. The WT-DFIGs and PV generation systems are the main power generation devices and the electrolyzer-BB act as a dump load using any excess power available to BB charging and produce H_2. The FC and BB system are the backup generation and supply power to the system when there is a power deficit. Simulation studies have been carried out to verify the system performances and the results obtained which show the effectiveness of the adopted control strategy. This latter justifies the usefulness of the DFIG in the possibility of management and the active-reactive power control, especially, operating as a local reactive power compensator.

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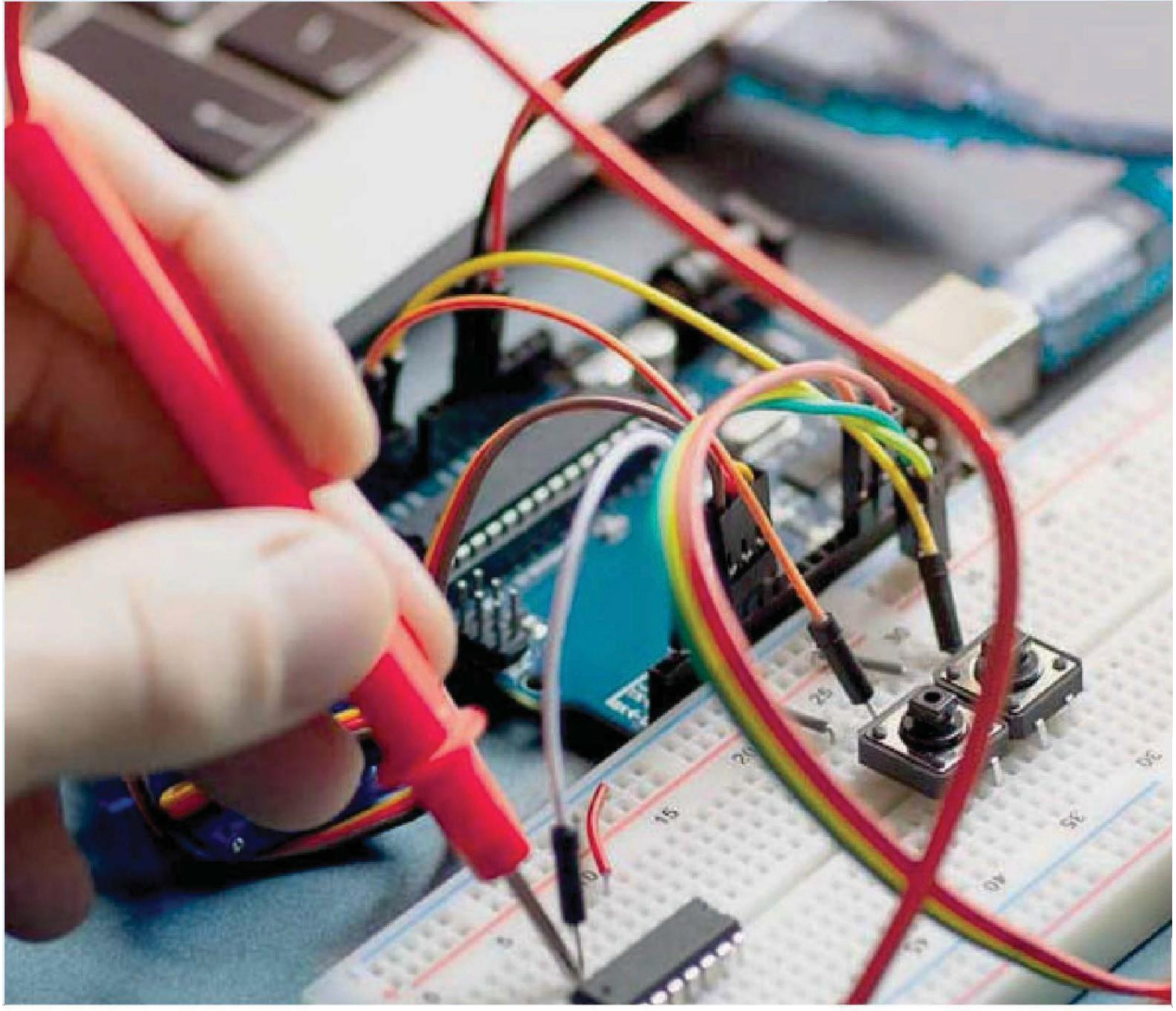

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Study and Design of AC and Hybrid AC-DC Micro grid: a Review

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ABSTRACT: The concept of smart grid and micro grid is a vast area of research now days. In this paper, various control strategies are presented forAC and hybrid AC-DC micro grid. Based on hierarchical control levels of micro grid, the different control strategies are discussedin local control, secondary control, and global control. Several research surveys are made for these methods. A proper control technique is required forconstant generation of all units. Comparisons are done between different controltechniques.

KEYWORDS - Micro grids, AC micro grid, hybrid AC-DC micro grid, hierarchical structure, control strategy, energy management system.

I INTRODUCTION

Today, the world has exposed extraordinary importance and desire of incorporating RESs and DGs into the power system network (electrical network) on account of numerous improvements. These improvements integrate extra energy related advantages (peak load decrement, better security of supply, prevents overcapacity, decrement of grid losses). In addition, renewable energy sources can build the efficiency of the plant significantly. Micro grid (MG) is a combination of collecting DGs that works together and normally operates synchronously with the grid connected but can also be operated as disconnected to an islanded mode of operation [1]. The MGs consists of distributed energy resources (WTs, PV, and Fuel Cell), storage devices (flywheels, super capacitors, and batteries), and loads for extensive control potential to the local loads. The MGs arrangement is linked to thelow voltage distribution system. With the growth of distributed RESs, several creations should be conducted in field of improvement of power system like smart grid for combination of distributed RESs and MGs, transformation of the local loads and power source optimization, and operation of manageable and dependable generation (active generators) to control the irregular availability of renewable resources. Research progress has always led towards solution for fulfilling the increase energy requirement. In priority to provide a constant progress in a viable way, a substantial part of the electrical power should be developed by the RESs. The major disadvantage is the intermittent character of the renewable energy sources (such as solar irradiation and wind variation). Therefore, the perception of renewable energy sources results in complicacy for operators in providing the same energy generation and demand which leads to poor power quality provided to the customers. The micro grids have the capability to enrich the consistency of electric power system if proper control techniques are implemented [2]. There are different distributed generations (DG) in micro grid that connects through the power electronic converters as the sources produces either AC or DC. The MG operation is managed by micro grid central controller (MGCC) through local controllers. In the grid-coupled operation mode, a synchronism energy layout is created between the DSO and the MGCC. The MGCC sets the power reference of system (micro turbine and diesel generator) instructing to satisfy the arrangement. In theislanded operation method, the micro grid should secure the regional supply and protection of energy [3].

The hierarchical control strategy is distributed with following levels: local control, secondary control, central and emergency control, and global control [2, 3]. The voltage, frequency, active power, and reactive power are the key variables in micro grid. The need for

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micro grid control is to attain good power distribution in both mode of operation. The controllers are also responsible for participation with optimized fabrication of micro sources in energy market and optimized utilizing cost of production. An energy management system (EMS) is required for consistent and stable operation of micro grid. The grouping of control strategies depends on hierarchical control. This review paper is to classify the work done in ac, hybrid ac-dc micro grids hierarchically with control strategies. This paper is arranged as follows: I and II section consist of ac micro grid and control of ac micro grid, respectively. Section III and IV represents hybrid ac dc micro grid and control of hybrid ac dc micro grid.

II AC MICROGRID

To accomplish the equilibrium between the generation and consumption, the MGCC should forecast the primary generation capability and the primary utilization requirement for the next interval. If the generation is more than the utilization, the power generation of the amenable DGs must be scale down. In the transient condition, the surplus power is exhausted insubstitute resistor loads when overvoltage occurs. If the generation is less than the utilization, then the stated DGs will be supplying the insufficient power or if necessary, t h e loads will be removed from the MG [4].

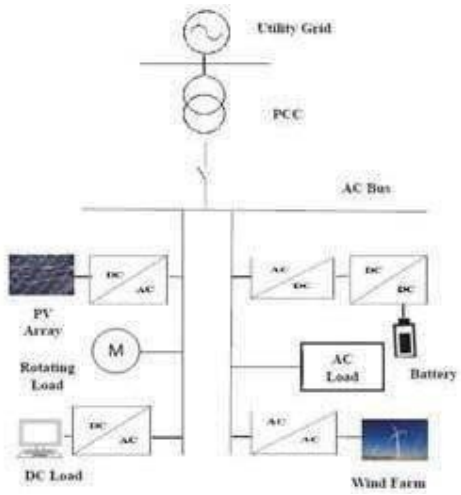

Fig. 1. AC micro grid architecture.

1.1 CONTROL TECHNIQUES OF AC MICROGRID

The control hierarchy consists of the following three stages:
Distribution management system (DMS), Micro grid central controller (MGCC), Local controllers (LC) [5].

1.1.1) Local Hierarchical Control

The local control is the quickest among all stages. It consists of distributed generation (DG) internal voltage and current control loops.It is engaged in decentralized way and maintains DGs stability. The local controller works to manage DGs in usual operation. It also maintains controlling of local signals. The reference voltage for local controllers is provided by droop controllers that operate as voltage source converter (VSC) [4]. The PI controllers are implemented in designing of control loops in it. The local controller takes care of inner control of DG. Usually, communication links are not required and thus lead to simple network and minimum cost. Local controllers are essential requirement for MG control. The important function of local controller is to manage DG to work in standard operation. The control of distribution of power between DGs could be added in this extent which is similar as the DG's output command.

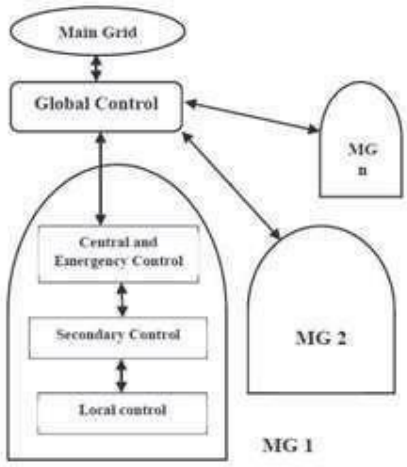

Fig. 2. Hierarchical control stages in MGs.

1.1.2) Conventional Droop Methods

The droop characteristics in conventional power system can be shown by P-f methods which are implemented for management of voltage and frequency of the islanded micro grid [10]. If Vs, Vg are the source RMS voltage and grid RMS voltage, respectively, 6 is rotor angle of the

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source and X is the total reactance of source and line, then electrical power P_e is given as

$$P_e = \frac{V_s V_g \sin\delta}{X} \quad (1)$$

The P-f droop method acknowledges reduction in frequency of the output voltage as the output real power of the inverter is increased. The conventional droop methods are not effective for distribution network because of its highly resistive nature. The main cause of droop control is to design the inertial capacity of synchronous machines to modifythe gap in generation and requirement by balancing the frequency [11]. According to [5,12, 13], the conventional droop method has many drawbacks which are described as that it has poor power sharing between DG units, poor voltage management of unfavorable loads through the approach of reactive power management, not suitable for nonlinear loads, droop equations are authentic simply for inductive lines.

1.1.3) Improved Droop Methods

There are lots of improvements to be needed in above droop control, so there are many control methods through which droop methods can be improved. They are listed as below.

1.1.4) Virtual Impedance Method

This control method is implemented in [12, 14]. The virtual impedance is used as a feedback of the primary control.

1.1.5) Adaptive Droop Control

This improved adaptive droop control exhibits a good performance towards load fluctuations by means of varying the load adaptively [15]. It provides the frequency stability with the changes in the load. It shows high robustness in making frequent changes in the load. The algorithm used in [15] conduct good coordination of power sharing of DG. It also avoids overload tripping. In [16], voltage regulation and reactive power sharing is improved by constant voltage strategy and conventional droop control method.

1.1.6) Angle Droop Control

In this strategy, for sharing the proportional load to DG, the output voltage of the converters is coordinated. The DG is injecting active and reactive power to the micro grid, which can bemanaged by voltage level and its angle [17]. The instantaneous real power p and reactive power q coming from DG to micro grid can be shown by these equations:

$$p = \frac{V * V_t \sin(\delta - \delta_t)}{X_f} \quad (2)$$

$$q = \frac{V^2 - V * V_t \cos(\delta - \delta_t)}{X_f} \quad (3)$$

From these equations it can be found that if difference in angle is less, then active power can be determined by 6 and reactive power can be determined by voltage level. 6 controls the active power and V controls the reactive power respectively, so the angle droop control equations are shown as

$$\delta = \delta_{rated} - m * (P_{rated} - P) \quad (4)$$

$$V = V_{rated} - n * (Q_{rated} - Q) \quad (5)$$

Where Vrated is the rated voltage and 6rated is the rated angle respectively, P is the active power and Q is the reactive power of the converter, m and n are the constants representing angle drop and magnitude drop. This method has low frequency variation than the frequency droop method.

1.1.7) Virtual Frame Transformation

This approach implements MG frequency and voltage as the communication network and activates the DG to distribute the load requirement without physical interconnections. The analysis of the operational range for DG with thought of active and reactive power distribution is presented in [18]. This transformation implements a linear square matrix to mention the real and reactive power equations. These powers are transformed to the virtual frame and it is given by

$$\begin{bmatrix} P_v \\ Q_v \end{bmatrix} = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \quad (6)$$

Similarly, frequency and magnitude of voltage source converter are also converted to the virtual frame given by the equations as

$$\begin{bmatrix} \omega_v \\ E_v \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} \omega \\ E \end{bmatrix} \quad (7)$$

This concludes that power output range is increased and improves micro grid stability.

1.1.8) Virtual Inertia Based Droop Control

This method is implemented for joining virtual inertia to the system. The virtual inertia is added to the system for preventing unfavorable

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triggering of relay because of over and under frequency. Despite the fact, the system stability is improved on virtual inertia-based sources, but effect is different [19]. The equivalence between virtual synchronous machine and frequency droop scheme of micro grid is referred in [20]. The zero-inertia virtual synchronous machines will be responded without low pass filter in power frequency droop control. It is concluded that the complicated structure does notalterthe performance of the virtual synchronous machine.

1.2) Secondary Control

It is the second level control loop. This layer enhances the duty of inner control loops to upgrade the power quality in MGs and to boost arrangement efficiency by eliminating steady- state errors. This layer is firmly operating with local and central/ emergency control groups [6]. In grid connected mode, the grid signals are used by micro grid as references for regulation of voltage and frequency. However, in islanded mode, the main grid cannot supply the reference signal to MG. During this situation, they may synchronize to achieve a coinciding operation utilizing multi master operation strategies. It also includes controls required to enhance the parallel operation presentation for DGs and inverter. There are several procedures to form a strong parallel operation of DGs and inverter through current/power sharing, droop control and masterslave control techniques. Low bandwidth communication may be needed to use in secondary control.

1.3) Central & Emergency Hierarchical Control

It is a highest-level control with important role in islanded operation mode. This system is responsible for secure and reliable duty of MG in both grids connected and islanded mode. The main purpose of this control is to search best unit commitment, regulation of voltage and frequency, reactive power supply, black start renovation, transmitting of available RES in normal mode and provide protection in emergency conditions. Previously joining to the utility grid, this central control synchronizes MG to make easier transition from islanded to grid connected mode. A review of distributed and centralized control is further defined below.

1.3.1) Distributed Approach

This approach permits the communication between the units for incrementing security, intelligence, and reliability. This technique is used at secondary and global controllevels. The local control has freedom to similarly; frequency and magnitude of voltage source converter are also converted to the virtual frame given by the equations as take decisions by communicating with each other [21]. The local controllers of distinct units are in communication with each other in distributedsystem shown in Fig. 3.

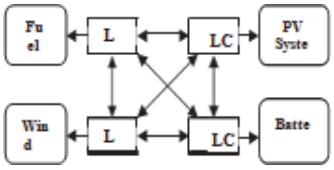

Fig 3. Typical distributed system micro grid

1.3.1.1) Multi-agent-based techniques

This technique uses an intelligent control system for interacting each other locally. The set points are determined that provide power quality and optimizes the operation of the system. The multi agent-based techniques are investigated in [21, 22, 23]. There are various autonomous agents that keep control and monitoring of components, in addition, they also interact with other agents. This system uses the Java Agent Development Environment (JADE), which simplifies the execution of agent systems[22]. The directory of Agent Identifiers is maintained, and it is managed by Agent Management Service (AMS). This system has two- way communication for all the units in the micro grid. The agent has the ability to change its environment by themselves. The multi gent system has various advantages such as robustness, autonomy, and limited use of data change and communication between units.

1.3.1.2) Model Predictive techniques

This technique deals in an optimization problem whose solution is based on forecasts and demand [24]. The

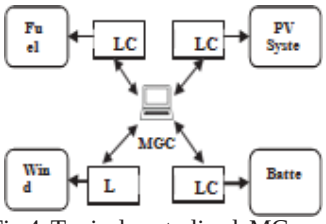

Fig 4. Typical centralized MG

forecasting of the demand, generation of DG units is done to formulate the optimal plan. Assuming the forecasting is correct, the controllers make the decision by themselves. The branch and bound technique are implemented to

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optimize the problem of model predictive control [25].The stochastic model predictive control algorithm is described in [24]. The dynamic programming method is used to solve the problem of optimization.

1.3.1.3) Consensus based techniques

In this technique, the information is divided in distributive way. The consensus algorithm is presented in [26, 27]. The process of updating information of agent it is shown as

$$x_i[t+1] = \sum_{j=1}^{n} d_{ij}\, x_j[t] \quad (8)$$

Where xi[t+1] is updated information of agent i, xj[t] is the local information of agent j. The dynamic consensus algorithm is discussed in [27]. The advantage of using this algorithm is communication is not required for all units; only neighboring units can communicate with each other. Flexible and reliable operation can be obtained by plug and play functions. It also does not require a devoted controller.

1.3.2) Centralized Approach

This approach includes MGCC which establishes a communication between local controllers and it. The bidirectional communication exists between them.

Here, the MGCC defines the control set-points to LCs which helps in optimization [5]. To maintain reliability and optimality of micro grid, the energy management system interacts with distribution system and receives the control set-points from it. The typical centralized micro grid system is shown in Fig. 4. The benefit of this approach is that the communication networks no too much engaged and provides online optimization.

1.4) Global Hierarchical Control

It is the uppermost control level for synchronizing the operation of multiple interconnected MGs and communication necessity with the utility grid. The interchange of power can be done with the main grid in this control. This control is slowest among all. The compensators provide control set-points (voltage and frequency) to the secondary control [28]. The MGCC takes care of entire MG for control of fault level, power flow, load shedding, connection, and disconnection. The control of active and reactive set-points is essential to optimize the micro grid operation. The optimization is generally depending on economic aspects.

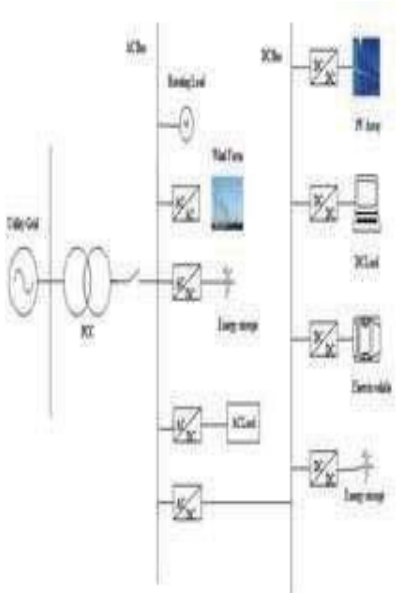

Fig. 5 Typical hybrid AC DC MG architecture

1.5) Intelligent Control Techniques

This control technique has a vast research scope in smart grid area. The intelligence control includes artificial intelligence, fuzzy logic, and neuron- fuzzy systems. An online intelligent approach has been introduced in [31], which implements a mixture of fuzzy and particle swarm optimization.

According to it, the parameters of proportional integral (PI) are automatically adjusted using online measurement fuzzy rules. The optimization problem can be solved using Genetic Algorithm, Ant and Bee colony shown in [31]. PSO is a way of direct search method and used to provide optimal solution in specified search space. PSO algorithm was developed with an idea for finding food for birds. The process suggests that the bird's group is finding food in different area. Theprocess can be explained as that each bit is found by two vectors X(t) and V(t). These two vectors represent the position and velocity of the bit at that time (t). The solution of the problem is the location of each bit X_i. All the bits rotate their places based on the experiences of the past. The algorithm concludes with following discussions as: easy to implement PSO online optimization, the PSO's result is high accuracy, optimal solution can be achieved easily, and more adaptable and robust structure can be attained.

A neural network-based approach is also an intelligent technique presented in [32]. This

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method is used for small wind turbine with gear box system. It is studied that the maximum power from wind turbine can be traced. It also gives the fastand accurate response. A supervised artificial neural network is used to evaluate wind velocity.

III HYBRID AC-DCMICROGRID

A hybrid ac-dc micro grid is an arrangement of both ac and dc grids attached through bidirectional converters as shown in Fig. 5. In this architecture, the DC micro grid is connected to an AC micro grid through bidirectional converter and an AC micro grid is connected to PCC. The role of power converter is very important in this type of structure. There are numerous challenges in hybrid AC-DC micro grid that are presented in [33- 37]. The main aim of hybrid micro grid is to control the power balance within the micro grid. It has distributed generation (DG) and energy storage devices on both sides of AC and DC bus.

The control and power management strategies are important for hybrid micro grid system [35]. It finds active and reactive power of storage devices and DG and therefore maintains frequency and voltage of micro grid. In autonomous mode of control of hybrid micro grid,it is difficult to attain power sharing by P-F and Q- V droop control methods.

2.1) CONTROL TECHNIQUES OF AC- DC HYBRIDMICROGRID

The centralized, decentralized and distributed primary and secondary control strategies are discussed in [36].

2.1.1) Centralized Primary and Secondary control

In centralized control, each unit is controlled from a single controller using a communication medium. The controller collects the data from various agents to achieve the optimization. A hybrid system with solar and wind energy source, a power control strategy is discussed in [39]. The MPPT control algorithm is used to attain maximum power by perturbation and observation method. The wind energy control design is an important aspect for it. Under a variable environment, voltage and power can be good managed in a hybrid system. More efficiency is obtained by a power sharing technique.

A centralized secondary control has various techniques described as further. An intelligent supervisory control is used in [40] to provide demand of load power for hybrid system. The SOC of the storage devices is maintained with the help of Fuzzy control. When the demands from the solar and wind does not meet the requirement then DG will be used. Fuzzy controller is used to determine the SOC of energy storage devices. An optimization based supervisory control is implemented for maximum use of energy sources [37]. To obtain optimal solution, a robust strategy is implemented. To find the charging and discharging of energy storage device, two-way control scheme is implemented. A coordination control of hybrid micro grid for autonomous and grid connected mode is described in [33]. The converters have to make a proper coordination with the grid for an uninterrupted supply. In grid connected mode, the important control is converter which maintains a dc voltage for variable loads. A coordination control algorithm is proposed for stable operation of micro grid. In isolated mode, the converter plays an important role for supplying voltage and frequency for ac grid. Here also, two level coordination control is implemented for stable operation. The hybrid system reduces the number of converters used in the system and the efficiency can be increased as the converter losses are less. A hybrid ac dc system can be located individually for homes and industries.

2.1.2) Decentralized Primary and Secondary Control

In Primary control, the two-control loop is used for voltage and current control. The current control is done through PR controller and dcvoltage control is done through PI controller.For proper load sharing, droop control method is required. By using equal virtual resistance, dc load sharing can be done [36]. The frequency of both thegrids are normalized as represented by equations

$$f_{pu} = \frac{f - 0.5*(f_{mx}+f_{mn})}{0.5*(f_{mx}-f_{mn})} \quad (9)$$

$$V_{pu} = \frac{V - 0.5*(V_{mx}+V_{mn})}{0.5*(V_{mx}-V_{mn})} \quad (10)$$

Where f_{mx} and f_{mn} are the frequencies on ac side and V_{mx} and V_{mn} are the voltage on dc side. In secondary control, decentralized method for autonomous hybrid structure for local and global power sharing is implemented [41]. Global power sharing (GPS) removes overstressed in DG. It is used when the sub grids are in symmetrical position. A distributed secondary control permits the communication

between local controllers in micro grid.

IV CONCLUSION

This paper exhibits an outline of control techniques in micro grid. The MG's hierarchical control system consists of four control levels: local or primary, secondary, central/emergency, and global controls. The primary control accommodates with each DG's internal voltage/ frequency and current control loops, whereas the secondary control extends upper level control loops i.e. the voltage and frequency control surrounded by a bus connecting MGs, supporting a load deviation. The central/emergency control deals as a micro grid EMS, and it is answerable for emergency control and overall protection plans. Lastly, the global control maintains the flow of power among the micro grid and the main grid, in gainful optimal operation. The drawback of decentralizedsecondary control can be solved by implementing distributed control where each local controller connects together and sends particulars to the smartgrid.

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CHAPTER1INTRODUCTION Introduction
Energyingeneralmeanscapacityorabilitytoproducework.Energyisessentialpartofourlifeandit'simpossibleto survivewithoutit. As timepassedbyandwithtechnologicaladvancementhumanswereabletousethisenergyinvariousforms.Consideringtheutilizationofenergy in dailylifeitwaspossibletocategorizeitasrenewableandnonrenewablesources.Thisthesisshedslightuponcombineuseof renewablesourcesi.e.solar&windenergy,hopingtodiscoveranddeterminetheextenttowhichenergygeneratedusingthistechnologyiscapableofsatisfyingthedemandofenergy.Usingthecombinationof PVandwindrenewablesystemhastheadvantageofusingitinregionshavinghigherwindspeedsandless sunnydaysandtheotherway round.
Thestatisticaldatainrecentyearsshowthat33%ofworldpopulationisnon-electrifiedandmostofsuchregionliesindevelopingcountries.Thewayinwhichsuchregioncanbeelectrifiediseitherbyextendingtheexistinggridorbydevelopmentofnewisolatedpowersystems usingalternativeenergysources?[1]
Theexistingpowersystemi.e.theonerunningondieselorcoal,isfacingmanyenergycrisesaswellascausingenvironmentalpollution.Additionally,thetransmissionnetworksinremoteareassufferfromhugetransmissionlinelossesandtechniquessuchascentralizedpowerflowandlowvoltagedistributioncausesinefficientuseoftheenergy.Becauseofalltheseexistingproblemstherei s arecenttrendoflooking towardsalternativesourcesofenergy.Thusrenewablesourcesarebecomingmorepopularandtheconceptofmicrogridcameintoexistencesoastoprovideclean,reliable,efficientandflexiblesourceofenergytotheenduser.

SupplyingpowertosmallelectricalloadsatremotelocationsorisolatedgridsHybridPV/Windpowergenerationsystemshavebecomeaprevalentoptionasitoffershighlyreliablesolutionforc

ontinuouspowersupply.Mostpreviousstudiesofthesesystemsconcentratedonlocalfeasibilityanalysis.Butthepracticalapplicationofthesesystems

Needistoconsiderparameterssuchasstability,controlandreliability.Therefore,inthisprojectcharacteristicof hybridPV/Windpowersystemsisinvestigatedbyapplyingsimulationmodeling.

Background andMotivation

Itis universallyacknowledgedthatthecontrolofpowerhasbeenacrucialproblemin microgrid.Inmicrogrid,thecontrolofactivepower,reactivepower,voltage,frequencyareallchallenges.Evenasmallmistakeincontrolofpowercouldcauseseveredamagetothewholepowersystem;forinstance,theNortheastBlackoutwhichhadcausedmillionsofpeopleawayfromtheelectricitythroughoutpartsoftheNortheasternandMidwesternUnitedStatesandtheCanadian provinceofOntario,happened

becauseofthecontrolproblemofthealarmsystem.Alackofalarmleftoperatorsunawareofthen eedtore-distributepowerafteroverloadedtransmissionlineshitunprovedfoliage,whichtriggeredaraceconditioninthecontrolsoftware[2].

Anotherinstanceisthe2012IndiaBlackout,inwhichtwoseverepowerblackoutscausedashortageof32GWandaffectedover300millionpeopleon30and31July2012[3].

Theproblemofpoweroutageshasmademanydisastersandtragediesinhumanhistoryandmostofthemhappenedduetothepoorcontrolofthepowergrid.Therefore,itiscrucialtomakesurethatpower isrunningundergoodcontrol.

Furthermore,theenvironmenthasbeenaffectedbythetraditionalpowergenerationmethods. However,microgridiscapableofintegratingrenewableresourcessuchaswindandsolar,which hasmuchlesspollutionthanthatofthetraditionalpowersources.Asanenvironmentalistwhoisinterestedinpowerandenergy,determinedtofocusingonthedesignandcontrolofthemicrogrid.

HybridAC-DCtechnologyconsistsofmostlytherenewablesources.Thesesourcesareavailable inabundantandcanbeutilizedtomaximumextentpossible.Thesetechnologiespreviouslyconsistedofonly Batteries,windturbinesanddieseltosupplytheload,butwas

notsufficientto managetheloadasthesystemwasnotstablein differentconditions.Thustoovercomethisproblem,controlleris usedalongwithadditionofPVmodule.OutputofthePVarraysdependsontheirradiationofthesunanditvariesdependingonthelocation.It'snecessarytocarryoutthetransientanalysisinsuch conditionswerenumberofnumberofDistributedEnergyResources(DER's)arepresent.Transientanalysiswillhelpinverifyingthestabilityofthissystemduringtheoccurrenceoffaultondifferentlocations.ThiscanbedonebyusingMatlabsimulation.

MicroGrid

Thereareanumberofdefinitionsformicrogrid.TheU.S.DepartmentofEnergydefinesmicrogridas"abunchofinterconnectedloadsanddistributedenergyresourceswithboundariesthatperformsasanentitywithcontrolcapability".TheWorkingGroup,MicrogridEvolutionRoadmapdescribesitasan"electricitydistributionsystemthatconsistsofdistributedgeneratorsandloadsthatcanbeoperatedcoordinatelyeitherwhileconnectedtothepowergridorwhileisolated"[4].FromthedefinitionofEUresearchprojects,microgridiscomposedoflow-voltagedistributionsystemswithdistributedenergyresources(PV,windturbineandfuelcell)andstoragedevicessuchasenergystoragesystemandflywheels[5].Theprimarypurposeistoensurelocal,reliable,andaffordableenergysecurityforurbanandruralcommunities.Italsoprovidessolutionsforcommercial,industrial,andfederalgovernmentconsumers[6].Furthermore,microgridcanbeconnectedanddisconnectedfromthegridtoenableittooperateineithergrid-connectedorislanded mode.Anidealmicrogridshouldalsoperformthefollowingbenefitsasshownbelow[7]:

"Ensurespowerquality,reliability,andsecurityforendusersandoperatorsofthegrid"

"Elevatestheintegrationlevelofdistributedand

renewable energyresources" "Costcompetitiveandefficient" "Enables smartgridtechnologyintegration" "Minimizecarbonfootprintandgreenhousegasemissionsby maximizingcleanlocalenergygeneration" Micro-sourceshavinglowcostandvoltage,highreliabilityarelaidoutatcustomersite.Thesemicro-sources arepowerelectronicdevicesandcontrollers thatinsurecontinuityofsupplytothecustomerandreciprocatewiththeutilities.Microgrids(MG)havesomedefinedcharacteristics asfollows: Decentralized Remotelydispatched Lessthan50-100MW Connectedwithdistributionsystem Microgridsarepossiblyimplementedintwoways;itcanbesimilartosmallelectricalgeneratortoprovidebackuppoweroracomplexsystemintegratedwiththeGridconsistingof generation,storageandpowermanagementsystems.Thesesystemsconsistofabunchoftechnologiesonthesupplysideaswellasondemandsideandlocatedatornearthelocationofloads.ThusMGtechnologyhaswideapplicationforlocalcontrollingelectricityusage.

Reasons forusingMicrogrid: Therearenumberof advantagesfortheconventionalarrangementofmodernlargepowersystem.Largegeneratingstationsareefficientlyoperatedastheyareinterconnectedbyhighvoltagetransmissionnetworkwhichoperateefficientlytotransferbulkpoweratlargedistanceswithlimitedlosses.Inmanycasesthedistributionnetworkisdesignedforunidirectionalflowandcanshelteronlycustomerloads.However,inrecentyearsalotofresearchisbeendonetoimprovetheMGtechnologyandthereasonsencouragingthemare[8]: Reductioningaseousemissions

Energyefficient Deregulationorcompetitionpolicy Diversificationofenergysources Climatechangeproblems Nationalpowerrequirement

InvestigationonthefeasibilityandbenefitsofMGiscarriedoutbyseveralresearchgroupsaround theworldasproblemslikedealingwithunbalancedloadsandharmonicsassociatedwithitneeds to berectified.However,thisreportdoes notconcentrateonaddressingsuchproblems;ratheritfocusesonmodelingtheMG'stoinvestigatethetransientandsteadystateresponse.

Aselectricdistributiontechnologyimprovesoverperiodoftime,noticeablechangesareseenthatwillaltertheenergyrequirements.Therequiredmodificationsarecarriedondemandsidewherehighavailabilityandefficiencyisneededaswellasinthesupplysidewherethedistributionnetworkandothercriticaltechnologiesmergetomaintain continuityofsupply.

Considerablechangesareseeninpowersystemsoperationsmainlybecauseofderegulationandduetodistributedenergyresources(DER).DERhasadvantagethatitallowsmicrosourcegenerationstoparticipateandalsoutilizerenewableenergysources(RES)likewind,solarorhydrotechnologies.Moreover,keepingthemclosetotheloadhelpsinreducingtransmissionlinelossesandavoidsnetworkcongestions.Alsopowercanbesuppliedwithoutanyinterruptiontotheusersandincaseofanyseveresystemcollapsethesemicro-sources canbeoperatedinislandingmode.

Usingcombinationofgasturbines,fuelcellsphotovoltaicsystems,windturbinesetc.microgrids upplyelectricity to thecustomers.Thestoragedeviceinmicrogridusuallyincludesbatteriesandflywheelsandthiscombinationissimilartorotatingreserveoflargegeneratorsinconventionalgrid.Itensuresbalancebetweengenerationand consumptionduringrapidchangesinloadorgenerationside.

Technicalstudiesneedto becarriedoutintwomajorfieldswhendistributedgeneratorsareinstalled.Firstly,withoutmaking largemodificationsinexistingsystemtheinfluenceofdistributedgenerators hastobedealwith.Secondly,newconceptsforutilizationofmicrogridhavetobegenerated. HybridAC-DCtechnologyconsistsofmostlytherenewablesources.Thesesourcesareavailable inabundantandcanbeutilizedtomaximumextentpossible.Thesetechnologiespreviouslycon sistedofonlyBatteries,windturbinesanddieseltosupplytheload,butwasnotsufficientto managetheloadasthesystemwasnotstablein differentconditions.Thustoovercomethis problem,controllerisusedalongwith additionofPVmodule. OutputofthePVarraysdependsontheirradiationofthesunanditvariesdependingonthelocati on.Thus,inthisprojectirradianceforNorthridgeandTexasisconsidered toseetheeffectsonthe powerflow ofsystem.It'snecessarytocarryoutthe transientanalysisinsuchconditionswerenumberofnumberof DistributedEnergy Resources(DER's)arepresent.Transientanalysiswillhelpinverifyingthestability ofthissystemduringtheoccurrenceoffaultondifferentlocations.This can bedonebyusingMATLABsimulation. / Figure1.1ClassificationofDGand technologyused[9]

OutlineoftheThesis
Basedontheresearchworkasexplainedinthepreviousssection,theoutlineofthethesischapterwillbe: Chapter2:PreliminaryTheoryThischapterdealswithabriefdiscussionon typesofmicrogrid.
Chapter3:LiteratureReviewThischapterdealswiththereviewontheresearchthathasbeendoneetilldate.

Chapter4:DesignofMicrogrid This chapterdealswiththedesignofenergyresourceslikewindpowersource,solarpowersource,aquaelectrolyzer,fuelcell,batteryandflywheel Chapter5: Result&Discussion Itanalyzesthesimulationresults fordifferent loadvariationsina microgrid.
Chapter6:Conclusion&FutureScope Itoutlines theconclusionandfuturescopeofwork.

CHAPTER2LITERATUREREVIEW ___
Followingpapersarereviewedandstudiedfortheimplementationofthehybridmicrogridsyste
m.
Microgridsareemergingasoneofthepromisingsolutionstointegratevarioustypesofdistribut
edrenewableenergysourceswiththeutilitygrid.Thoughtheexistinggridsare ACgrids,today'se
lectricalloadscomprisingofpowerelectronicbasedequipmentsanddistributedrenewableen
ergygenerationmakeDCmicrogridsmoreattractive.

However,anindividualACmicro gridandDCmicrogridrequires
multipleconversionsofpowerattheuserendforDCloadsandACloadsrespectively,resultinginl
essefficientsystem.Thus,hybridAC/DCmicrogridseemstobethebestsolutiontoavoidsubstan
tialenergylossesinmultipleconversions.However,thereareseveraltechnicalchallengesinthei
mplementationofhybridAC/DCmicrogrid,whichneedtobeaddressed.Thispaperpresentsan
overviewofhybridAC/DCmicrogridanddiscussestheimportantkeyissuesandchallenges to
beovercomeforits practicalimplementation.[13]
Theincreasingdeploymentofdistributedgenerationsystemsinpowersystemshybrid AC/DC
microgrid.Many microgridsareusedfor interlinking ac/dcconverter
withproperpowermanagementandcontrolstrategy.Duringtheislandingoperationofthehyb
ridAC/DCmicrogrid,theICisintendedtotaketheroleofsuppliertoonemicrogridandatthesam
etimeactsasaloadtoothermicrogridandthepowermanagementsystemshouldbeabletoshar
ethepowerdemandbetweentheexistingacanddcsourcesinbothmicrogrids.Thispaper
considersthepowerflowcontrolmanagementissuesamongthemultiplesourcesdispersedthr
oughoutbothacanddcmicrogrids.Thenewmethodisproposedwhichisthedecentralizedpow
ersharingmethodinordertoeliminatetheneedforanycommunicationbetweendistributionge
nerationormicrogrids.Thishybridmicrogridallowsdifferentacordcloadsandsourcesshouldb
eflexiblylocatedinordertodecreasetherequiredpowerconversionsstages
andhencethesystemcostandefficiency.

Thedecentralizedcontroloperationanddroopcontrolmethodisusedforbettercontrolstrategy.Theperformanceoftheproposedpowercontrolstrategyisvalidatedforsmallsignalstabilityanalysisanddifferentoperatingconditions,usingsimulationstudiesinMATLABsoftware.[14]
ADCmicrogridsystemhasbeen
proposedasapowernetworkthatenablestheintroductionofalargeamountofsolarenergyusingdistributedphotovoltaicgenerationunits.Totestthefeasibilityofthesystem,wehavedevelopedademonstrationfacilityconsistingofsiliconphotovoltaic(Si-PV)units,copperindiumgallium(di)selenidephotovoltaic(CIGS-PV)units,concentratorphotovoltaic(CPV)units,anaerogenerator,andaredoxflowbattery.Theredoxflowbattery,akeycomponentforsupply-demandadjustmentinthemicrogridsystem,successfullybalancedsupplyanddemandinthegridbyitsrapidcharge-dischargeabilityevenunderthefluctuatingconditionofpowergenerationandconsumption.[15]
ThispaperproposesanewDCmicro-gridsystem,whichfullyutilizestherenewableenergyandelectricvehicleforsmartenergydelivery.TheproposedDCgridincorporatestheACsupplymodule,standbyenergymodule,renewableenergymodule,andstorageenergymoduletogether,
toexecutetheenergydistribution.Hence,thisgridsystemcanofferahighqualitypowerfortheth reetypesofloads,namely110VACsingle-phaseoutput,48VDC
output,and100VDCoutput.Thecontrolstrategyofthegridsystemforperformingsmart
energydeliverywillbediscussedinthefullpaper.Thesimulationresultswillbealsogiventoverify thefouroperation modesofthegridsystem.[16]
Thispaperdiscussesabriefhistoryofelectricity,specificallyalternatingcurrent
(AC)anddirectcurrent(DC),andhowthecurrentstandardofACdistributionhasbeenreached.DCpowerwasfirstproducedin1800,buttheshifttoACoccurredinthe1880'swiththeadventofthe transformer.Becausethedecisionsfordistributionweremadeover100yearsago,itcouldbetimetorethinkthestandardsofpowerdistribution.ComparedtotraditionalACdistribution,DCmicrogridsaresignificantlymoreenergyefficientwhenimplementedwithdistributedgeneration.
Distributedgeneration,oron-

sitegenerationfromphotovoltaicpanels,windturbines,fuelcells,ormicroturbines,ismoreefficientwhenthepoweristransmittedbyDC.DCgeneration,pairedwiththegrowingDCloadprofile,increasesenergysavingsbyutilizingDCarchitectureandeliminatingwastefulconversions.Energysavingswouldresultfromalowergridstrainandmoreefficientutilizationoftheutilitygrid.DCdistributionresultsinamorereliableelectricalserviceduetoshorttransmissiondistances,highservicereliabilitywhenpairedwithon-sitegeneration,and efficient storage.Occupant safetyisaperceivedconcernwithDCmicrogridsduetothelackof knowledgeandfamiliarityinregardstothesesystems.However,withproperregulationanddesignstandards,buildingoccupantsneverencounter voltagehigher than24VDC, whichissignificantlysaferthanexisting120VACintheUnitedStates.DCMicro gridshaveseveraldisadvantagessuchashigherinitialcostdue,inpart,tounfamiliarityofthesystemaswellasagenerallackofcoderecognitionandefficiencymetricrecognitionleadingtodifficultcertificationandcodecompliance.Casestudiesarecited inthispapertodemonstrateenergyreductionpossibilitiesduetothelackofmodelingabilityincurrentenergyanalysisprogramsanddemonstratedenergysavingsofapproximately20%.[17] Renewablepowergenerationandtheprospectoflarge-scaleenergystoragearefundamentallychangingthetraditionalpowergrid.Arisingchallengesoccurintermsofenergymanagement, reliability,systemcontrol, etc.Microgrid,asanactivesubsystemofmodernpowergrid,hasrevealeditspromisingpotential indealingwithintermittentcleanpowergenerationandemergingenergystorage,partiallybroughtbyelectricalvehiclebatteries.

Inthischapter,theconceptofmicro gridisintroduced.The main focusisplacedonthebasicissuesofcontrol,operation,stability,andprotectionofDCmicrogrids.[18] Three-phaseACpowersystemshavebeenindominantpositionforoverhundredyearsduetoinventionoftransformerandtheinherentcharacteristicfromfossilenergy-drivenrotatingmachines.However,thegradualchangesofloadtypesanddistributedrenewablegeneration(DRG)inAClocaldistributionsystemsprovidefoodforconsiderationofaddingDCnetworks.Renewable sourcessuchas fuelcellsandsolarphotovoltaicareDCinherentandshouldbeconnectedtoACgridthroughDC/AC

conversiontechniqueswhereassomeACinherent renewablesourceslikewindgeneratorsalsoneedDClinksintheirconversionsystemstoincreaseefficiencyandmitigatepowervariationcausedbyintermittencyanduncertainty.ThedisadvantageofACgridsforconnectionofDCinherentsourcesandloadsaswellasACloadswithDClinksisthatadditionalDC/ACorAC/DC convertersarerequired,whichmayresultin efficiencylossfromthereverseconversion.In theotherhandDCgridsareresurgingduetothedevelopmentanddeploymentofrenewableDCpowersourcesandtheirinherentadvantageforDCloadsincommercial,industrialandresidentialapplications.Thenumberofpowerconversionsina DCmicrogridhasbeensignificantlyreducedtoenhancesystemenergyefficiency.Amorelikelyscenarioisthecoexistenceofboth.[19]
ThispaperpresentsahybridAC/DCmicrogridconcepttodirectlyintegrateDC/ACrenewablesourcesandloadstoDC/AClinksrespectively.Thehybridgrideliminatesmultiple DC-AC-DC&AC-DC-ACconversionsinanindividualAC&DCgrid.Thehybridgridincreasessystemefficiency,eliminatestheembedded AC/DCandDC/DCconvertersinvarioushome,officeandindustryfacilitieswhichcanreducesizeandcostofthosefacilities.Thebasicarchitectureofthehybridgridisintroducedinthispaper.Differentoperationmodesofthehybridgridarediscussed.Thevariouscontrolalgorithmsareinvestigatedandproposedtoharnessthemaximumpowerfromvariousrenewablesources,tostoreenergysurplus duringlowpeakloads,toeliminateunbalanceprobleminAClink,tomaintainvoltagestabilityandsmoothpowertransferbetweenACandDClinksundervarious generationandloadconditions.Aprototypeofthehybridgridunderconstructionispresented.Somesimulationandtestresults arepresented.[20]
ConsideringtheadvantagesofDCmicrogrids,theextensionoftheconventionalACdistributiongridcanbeimplementedusingaDCmicrogrid.Thisjustifies therealizationofahybridAC/DCmicrogrid.Inthepresentstudy,anewglobalsolutionispresentedtoimprovethepowerqualityandtofullycompensatethereactivepowerofanACmicrogridusingDCbuscapacitywhileintroducinganewdesignforahybridAC/DCmicrogrid.Inthenewdesign,backto-backconnectionsoftwoseriesandparallelconverters,aswellasthepresentationofnewcontrollersandsimultaneousutilizationofanearthingswitch,areproposed.Theproposedmethodguaranteesthequalityofthedelivered

voltagetoconsumers andthedrawncurrentfromthenetworkaccording totheIEEE-519andIEEE-1159standardsunderdifferentpowerqualityproblems(e.g.,interruptions,sags,harmonics,andanyvariationinvoltage/current signalsfrompuresinusoidal).Throughtheproposeddesignofthenewhybrid AC/DCmicrogrid, asanewfeature,theoperationofthenetworkin islandedmodecanbeachievedinaccordancewithpowerqualitystandardseven in theworstloadqualityconditions.

Itshouldbenotedthatincommonhybridmicrogridsinislandedmode,thedeliveredvoltagequalityisproportional tothequality oftheconsumer'sloadcurrent.Anotherpossibilityoftheproposeddesignistheinstantaneous VARcompensationofnonlinearandinductionloadsofconsumerstokeepthepowerfactorofthe distributiontransformerclosetounitvalue.Simulationresultsindicatethattherearеacceptable levelsofcompensationfordifferenttypesofpowerqualityproblems. Totalharmonicdistortionsandtotaldemanddistortionsarebelow3% inboththegrid-connectedandisolatedmodesofthehybridAC/DCmicrogrid.[21] ThispaperproposesReal-timeEnergyManagement System(EMS) foraresidentialhybridac/dcmicrogrid.Theresidentialmicrogridisorganizedintwodifferentdistributionsystems.Adcdistributionbuswhichinterconnecttherenewableenergysources(RES), energy storagesystems(ESS)andthebuilding'scommonfacilities; whiletheapartmentsaresuppliedbyanacdistributionsystemconnectedtothegrid.Thisarchitectureavoidsanymodificationsintheelectricalinstallationthatsuppliesenergytotheapartments.Apuredcvoltagesupplyisnotyetafeasibleapproachforresidentialbuildings.Thisarchitectureincreasestheoverallefficiencyofthedistributionbyinterconnectingthe RESandESSthoroughadcdistributionbus,andthereforeavoidingunnecessarydc/acconversionstages.Thereal-timeEMSperformsa24hoursaheadoptimizationinordertoschedulethecharge/dischargeoftheESS,andtheenergyinjection/consumption fromthegrid.TheEMSestimatestheRESgenerationbasedontheweatherforecasting,together withstochasticconsumptionmodellingofthebuilding.TheEMSarchitectureandtheresidentialmicrogridhavebeenimplementedandtestedinalaboratoryscalesetup.Theresultshaveshownhowtheoperationalcostsofthesystemareeffectivelydecreasedby28%,evenwithnonaccurateestimationoftheRESgenerationorbuildingparameters.[22] Complexcircuitryofelectronicinfrastructureofcompactmicro-gridswithmultiple

renewableenergysourcesfeedingtheloadsusingparalleloperation ofinvertersactsasadeterrentindevelopingsuchsystems.Thispaperdealswithapplicabletechniquesreducingthedrivingcircuitsinparallelpowerinvertersusedinmicrogridsystem(MGS),mainlyfocusedonthedistributedgeneration(DG)inislandedmode.Themethodintroducedinthispaper,givesaminimalandcompressedcircuitrythatcanbeimplementedverycost-effectively withsimplecomponents.DCmicro gridsareproposedandresearchedforthegood connectionwithDCouputtypesourcessuchas photovoltaic(PV),fuelcell,andsecondarybattery. Inthispaper,theelectronicinfrastructureofmicro-gridisexpressed.Thendiscussedthereasons foritscomplexityandthepossibilityofreducingtheelementsofelectroniccircuitsareinvestigated.Thereasonforthisisinordertocompact DCmicro-gridsystemforelectrification toplaceslikevillages.DigitalSimulationinMatlabSimulinkisusedtoshowtheeffectivenessofthisnoveldrivertopologyforparalleloperatinginverters (NDTPI).[23] Itpresentsdesignandanalysisofoptimizedgrid-tiedsolarPV/fuelcellhybridpowersystemtomeettheelectricloadsofacommercialBuilding(AdministrationBuildingattheUniversityofSharjah)in thispaper.ThebuildingAC primaryloads weredeterminedfromthebuildingenergyaudit.Therenewableresources inSharjah,therenewableenergytechnologyoptions,thesystemcomponent costs,andtheconstraintsweredetermined.Anintegratedmodeling,simulation,optimization, andcontrolstrategies were used totesttheperformanceandthecostoftheproposedgrid-tiedhybridsolarPV/fuelcellpowersystem.Theeffect ofthesolarPV powercapacityontheperformance(renewablefraction,costofenergyandgreenhousegasemissions)ofthegrid-tiedsolarPVsystem wasinvestigated.Theresultsshowthatthesolargrid-tiedsolarPV/FuelCellgridpowersystemmeetsthedailyandyearlyelectricaldemandofthebuildingwithsomeoftheexcesspower(fromthesolarPVandfuelcell)soldbacktothegrid.Thegrid-tiedsolarPV/fuelcellhybridpowersystemoffersagoodpenetrationofrenewableresources(40.4%renewablefraction),lowlevelisedcostofenergy(71 $/MWh),andlowcarbondioxide(CO2)emissions(133kgCO2/MWh).Theintegrationofrenewablepowersystemswiththeutilitygridisoneofthebeststrategyandefficientmethodtoincreasethepenetrationofrenewableenergyintheenergymixwithaffordablecostofenergy,reducethereliianceonfossilfuelsandreducetheenvironmentalimpacts(greenhousegas emissionsreductions).[24]

Itpresentsanapproximate73kWhybridmicro-gridsystemdesignedwithPV,FC,andbatterystoragesystem.Inordertotestthesystem'sperformanceinoff-grid mode,a43kWacloadisconnectedtotheproposedsystemviaadc/acinverter.Itisshownthatthesystemyields stableoutputvoltageandcurrent. Moreover,thestabilityofthesystemis validatedbyconnectingittotheIEEE13bussystem,andanapproximateof73kWrealpowerisaddedtothegrid.Underthison-gridmode,theproposedsystemalsoremainsstable.Hence, theproposedhybridmicro-gridsystemmay bethefuture solutionfortheongoingpowercrisisintheuniverse.[25] It reportasystematicliteraturereviewofcontrolaspectsinac,dc,andhybridac-dcmicrogrid.Therehasbeenanextensivevolumeof research onthevariousaspectsofthemicrogrid.Thecontrolaspectsofthemicrogridarethemoststudiedtopicsofinterest.Withoutastableandaccuratecontrol,themicrogridimplementationisnotfeasible.Althoughacmicrogridhasbeenawidelyresearchedtopic,dcandhybridac-dcmicrogridsaregraduallygaininginterestoftheresearchersfromtheperspectiveofreliability,minimizationofconverterlosses,andefficiency.Thecontrolhierarchyofthethreecategoriesofmicrogridfollowsasimilarpattern,whilethedifferenceliesinthedroopcharacteristicsinvolvedintheprimarycontrol,andtheapplicationofsecondaryandtertiarycontrolfordifferentoperatingmodesinthem.Theheart ofthemicrogridcontrolistheEMSinthecaseofcentralizedapproach.Oncethecentralcontrollerfailsinitsoperationduetothecommunicationerror,theprimarycontrollerstoocannotbefunctional.However,incaseofdecentralizedsecondarycontrol,thereisnoneedforacentralizedcontroller'scommandtooperateprimarycontrollers.Thedecentralizedsecondarycontrolislessreliablethanthecentralizedone,astheLCscannotfunctionoptimallyduetothelackof informationaboutthesystemoperatingstate.

[26] ItpresentsTheperformanceofUPQCunderdifferentloadconditionshasbeenstudiedandcomparedwithmicrogrid sidedisturbancesandgrid sidedisturbances,itis observedthattheharmonicsinloadcurrentisreducebelow5%inallcasesandalsothecompensationofvoltagesagandswell.Thesimulationresult showsthatUPQCconnectedtogridwithnonlinearloadcancompensatevoltagesag,swellandalsoreducetheloadcurrentharmonicsto2.33%.TheimplementationofmicrogridwithUPQCmakesanadvantagethatitcancompensateallthepowerqualityandalsoreducetheloadcurrentharmonicsto3.48%. FromtheanalysisitisfoundthatUPQCconnectedtoutility

andmicrogridcancompensateallthePQissuesindistributionside.Moreover,incaseof anymajorfaultorpowerdisturbanceinthemaingrid,theMicrogridswitchesovertostand-alone modewhilestillfeedingpowertothecriticalloadseffectively.[27]
Itpresentsapaperconcernedwiththedesignofanautonomousmicrogridsystemintendedforu seinaresidentialapplication.
Forensuringahighlyaccuratesolution,theloadswereanalyzedandappropriateloadcurveswer econstructedfora12-monthperiod.Theprimaryobjectivewastheminimizationofthetotal NPCoftheoverallsystem,whilenoloadsheddingwasallowedamongstafewothertechnicalconstr aints.Theoptimizationprocedureevaluatedthousandsofdesignchoicesrangingfromvarious capacitiesoftheselectedenergyresourcesandconverteraswellastwotypesofbatteriescombin ingdifferenttechnicalcharacteristicsandcapitalcosts.Theanalysisconcludedthat,forthegiven loads,thebestsystemdesignistheonecomprisedofaPVarraywith acapacityof 15.3kW,a17kWdieselgenerator,57kWh of
lead-acidbatteries,andaconverterwithapowerratingof6.93kW;thetotalNPCofthissystemeq uals£56,264.Additionally,thecarbonemissionswerecalculated,andthestudyindicatedthatth eoptimalsystemdesigncorrespondsalsotothesystemwiththeleastcarbonemissions;thisisan on-negligiblefactortowardsimprovingtheenvironmentalconditions.Theoptimalsolutionsu pportstheargumentthat,forsuchapplicationswithnopossibilityofgridconnection,ahybridsys temconstitutesacheaperandenvironmentallyfriendlysolutioncomparedtothesolutioncom prisingofastandalonedieselgenerator.Additionally,asensitivityanalysisrelatingtodieselpric esandsolarirradiationwasperformed.Theanalysisconcludedthatthesetwoparametersarech aracterizedbyaninverselyproportionalrelationship,whileshowingthatdieselfuelpriceincreas eleadstoanincreaseofthePVarrayandconverterrating.[28]
Itreportsdesignandcontrolofastandalonemicro-gridsystemwithaPVsystemandWECSwere proposedin thiswork.Tocontrol andharvestthemostpowerpossiblefromthePVsystem,fuzzy logic-basedMPPTwasusedfora boostconverter.ThePV
system'soutputprovidedaconstantDCbusvoltagetoabatterystorage
systemthatwasregulatedbytwoPIvoltageandcurrentcontrolloops.Thecontrolsystemisinten dedto
achievetheloadinallcases.Whentheenergygeneratedbythe PVpanelexceedstheenergyrequi redbytheload,theexcessenergyisusedtochargethebatteries.WhenthePVpanel'selectricityisi nadequatetofulfilltheload'sdemands,theextrapoweris

drawnfromthechargedbatteries.Furthermore,thecontrollerisemployedtoprotectthebatterybanksinallscenarios,includingnormal,overcharging,andoverdischargingscenarios.Eachcaseshouldbehandledappropriatelybythecontroller.Regardless ofthebattery'sstateofcharge,thecontrollerperformsasexpectedundernormaloperatingconditions(20%<SOC<80%).AspecificorderisdeliveredwhentheSOChits80%,whichturnsoffthePVpanelandthewind turbine.ThePVpanelandwindturbinecannotbeconnecteduntiltheSOCdropstoasafemarginof75%inthiscontroller.Othercommandsaresentouttoturnofftheinverteranddisconnectthe loadswhenSOCfallsbelow 20%.Theinverter'spowerisswitchedoffuntilthebatteriesare chargedagain toasuitablevalue.Thedesignedstand-alonemicrogridsystemandtheircontrollerssolvedtheproblemofsupplyingtheelectricenergytoremoteareaswheretheelectricalgriddoesnotexist.[29] They study'smainobjectiveistoensurestableDCbusvoltageby providinganeffectivesystemforDCmicro-gridpoweredbyafuelcellandsolarpanel,andthebackupstorageunit(SC).TheparallelemploymentofPVandFCensuretotheloadissustainablesupplying.Theresearchfocusesmostlystabilizingthe DCbusvoltage,moreover,employingtheFC,solarpanelandSCintheenergymanagementapproach,takingintoaccountthe energeticpropertiesofthesesourcessuchasitspowerandenergydensityanditsdynamics.Nonlineardifferentialflatnessstrategyfor DCmicrogridbasedonarenewablesourcewithafuelcellprovidesexcellentDC-linkstabilization.Thesuper-capacitorcanmovetheloadforward,regarding thecharacteristicsofthemain sources,bysupplyingastrongerpowerresponsetotheload.Duringtheimportantstepsoftheload,thesuper-capacitorofferstheenergybalancerequiredduringthetransitionoftheload.Also, distributedpowersystemsimprovepowerqualityandefficiency.[30] ThispaperhasdealtwiththeoptimaldesignofhybridAC/DCMGs.Atailor-madeGAhasbeenproposedtosolvethedesignproblemwithrelativecomputationalsimplicity,whileadetailedACOPFwiththeabilitytocapturecontingencieshasbeenutilizedtoevaluatethedesigncandidatesdeterminedbytheGA.Thisapproachprovidesabenefitoverotherdesigntoolsfoundintheliterature,asitensuresthattheoptimaldesigncandidatesatisfiesalloperationalconstraintsoftheMG.AgeneralizableAC/DCMGhasbeenutilizedfordemonstratingthebenefitsoftheapproach.Additionally,throughappropriatesimulationsthepaperindicatesthebenefitin costsavingsofutilizing

different typesofstorage
devices(i.e.amixofhigh/lowpower-energy)andappropriatelydiscriminatingloadsintocritical andnon-critical.Asfuturework,sincetheproblemunderinvestigationisthat ofoptimaldesign,itisnecessarytoconsideramuchlongerplanninghorizon(i.e.atleastseveralre presentativedays/weeks)toensurethatthesystemisnotoversizedduetousingapeakday.Itisal soofparamountimportancetocapturewithinthisplanninghorizontheeffectsof stochasticitybothforloadsandnaturalresources.Toachievethis,itisanticipatedthatanappropr iatedecompositionmethod,splittingtheproblem into twosubproblems(i.e.oneper subgrid)wouldallowamuchlongerhorizontobesimulatedwithconsiderablylesscomputation alexpense.[31]
Theyproposedamicroelectricalpowergridsystemcomposedofanoptimalcontrollerdesignus inganMBAalgorithm.Thisstudiedcontrolledpowersystemmainlyincludeshybridwind/fuelce llgeneration
unitwhichfeedingbothdynamicandstaticloads.Theseloadsarefedbythefuelcellandthewind powergenerationsystem.Athighvaluesofwindspeedwindpoweractsasthemastersourcethat suppliestheloadsandstorehydrogenintheFCviatheelectrolyzer.Consequently,atlowvalueso fthewindspeed,theFCactsasaslavethatsuppliestheloads.Theproposedmicro gridsystemissimulatedusingSimulink/MATLABsoftwareandistestedinstepvariationsofwind speed,IMrotorspeed,IMtorque,andstaticloadcurrent.Theresultsofthesimulationshowthatt heproposedgenerationsystemsuccesstosupplytheloadsperfectlyunderalldisturbances.Itisi ndicatedthattheperformanceofthemaininverter controllerisexcellent,astheloadpower responseshavelowovershootaccompaniedbysmall settlingtime.[32]

CHAPTER3CLASSIFICATIONOFMICROGRID Overview:
MicrogridsareclassifiedasACsystems,DCsystemsorHybridsystemsbasedonthepowerdrawn fromit.Any
ofthesetypicalmicrogridisidenticaltoasmallpowersystemconsistinginterconnectedcompo nentslikeDGunits,loadsandstoragedevices.AlthoughcontrollinglargenumberofDG'sischall engingconsideringthesafetyandefficiencyofthesystem,moderntechnologyplaysacrucialrol einovercomingtheseproblemsusingpowerelectronicdeviceswhichinterferewithDG'stocrea teanarchitecturecalledasmicrogrid.Asdiscussedearlierthecomponentsofmicrogridareconn ectedtopowerdistributionnetworkusingpointofcommoncouplingandtherebyitappearsasa singleunittotheentity.Theclassificationbasedonpowertypeisshown below: / Figure3.1
Classificationbasedpowertype:ACorDCmicrogrid[10] DCMicrogrid:
RecentlyDCmicrogridhasarisingpopularityincomingyearsandprovidesmostattractiveoptio nsoverACmicrogridstructure.DCmicrogridinheritstwomodesof

operation:grid-connectedmodeandautonomous modeandhasseveraladvantagesof ACmicrogrid.
DGsysteminMG'smostlyconsistingofPYunits,fuelcellsWindturbinesoranyotherrenewableenergyresource.Itutilizesthedcoutputvoltagefromitsstoragedevicesandthusitsutilizationcanbeeasilycarriedoutbyhelpof
voltageregulator.Thereisnoneedofadditionalsynchronizationsystemfortomatchthevoltagemagnitude,phaseorfrequencyasneededforACsystems.Thusbecauseofbettercompatibility,higherefficiencyandbetterstability&reliabilityDCmicrogridisanemergingoptioninmicrogridtechnology.

Atypicalexample ofDCmicrogridis asshownbelow: /
Figure3.2StructureofbasicDCMicrogrid[11]
Asseen,thePVpanelsareconnectedtotheDCbusviaDC/DCconvertersandthewindturbineisconnectedusinganAC/DCrectifier.AlsotwobatteryunitsactingaspowerstorageelementareusedtostoreexcesspowerbyhelpofDC/DCconverters;thisallowschargingandddischargingasandwhenrequired.AsseenbymakinguseofinterfacingconverterstheloadcanbesuppliedtotheACgrid.

ACMicrogrid: AlthoughDCmicrogridswerewidelypreferred initiallybecauseofitseasyutilization,ACmicrogridshavewonoverDCsystemsfor severalreasons.ACsystemcaneasilyalter thevoltagelevelstherebyprovidingflexibilitytothegeneration,transmissionandconsumption side.AlsothecostofACequipmentisrelativelycheaperthanDCequipment.AsACdistributionn etworkispredominantlypreferredworldwide,integrationofACmicrogridin distributionnetworkaddsexcellentbenefittotheconventional power system.ACmicrogridcanbeutilizedandextendedtoruralaswellasincitiesandtherebygenerate reliablepowerincaseof occurrenceofanydisturbances.Thusitcan alsobeeasilyoperableinoffgridmode. Abasicexampleofmicrogridisasshownbelow: / Figure3.3StructureofbasicACMicrogrid[11] Fromthetypicalexampleshownaboveitcanbeseenthatthemicrogridisconnectedtothemains usinganintelligenttransferswitch,whichallowstheMGtooperateingridconnectedaswellasoff gridmode.AsseeninthefigureeachDGconsistofinverter

systems,amicro-sourcetypicallyphotovoltaic,windturbinesandfuelcellsetc.andenergystorage systems.Thistypeofmicrogridstructuremakeslesslossesandflexibilityinpowersupply.

HybridAC/DCMicrogrid: Althoughdcmicro grid havemanyadvantagesoverAC microgrids,thistechnologyisnotyetacceptedcompletelyandisnotenoughtochangetheexisting systemdrastically.SinceACsystemispredominantlyintoexistencethereforeitismorelikelythatacombinationofAC&DCmicrogridsystemcansolvetheexistingproblemsinefficientway.Thusthereasonsforusinghybridconceptformicrogridareasfollows: LoadtendencyfromAC toDC:
Thepowersupplysystemisdesignedtosupplyresidential,commercial&industrialloads.Initially theacanddcloadsandgenerators
weredesignedsuchthattheycanadapttobothADandDCsystemaswholebutverycomplicated andinefficientsystemhadto
beinstalledeventuallysufferingheavylosses.LateronACsystemsbecamestandardanddominant sourceforenergysupplyinallsectors,sincetheneverythingwasdesignedkeepingACsystem anditsshortcomingin
mind.Also,theDCloadswerestillbeingusedbyconnectingthemwithAC/DCconverterneglecting theefficiencyofsuchconverters.

ThedevelopmentofpowerelectronicdevicesanditscontroltechniqueshasledtochangeinloadtendencyfromACtoDCbecausenowit'spossibletoachievehigherefficiency,flexibilityandreliability inimplementing theDCsystems.Thechange
isalsotakingplaceasmostofthemodernelectricalequipmentandpowersystemsmake useofDC
systemfortheiroperation,e.g.computers,printers,hometheaters,refrigerators,airconditioners,washingmachines,commercialbuildings.Ontheother-hand,manydevicesmakeuseofAC/DCconvertersfortheiroperationtoadjustthespeedandsaveenergy.AlsothemoderntechnologyisinclinedtowardscreatingenergyefficientdeviceswhichmostlymakesuseofDCcomponentsandsystems.Therefore,DCloadscanbenowefficientlyutilizedandintegratedwith exitingACsystems. Recenttrendofrenewableenergyresources:
WiththegrowingresearchinRES3.technologysuchasPVsystems,Windturbines,Energystorage system,fuelcellsandtremendousdemandforenergyisthereasonforlookingatalternativeoptionstosupplyenergyefficientlytotheincreasingpopulation.

ThusthereisincreaseinutilizationofDCsystemsinexistingACpowersystemsandupgradationl eadingto hybridtechnologycomingintoexistence. Powerconversion in ACandDCsystems: Thepower conversionin ACandDCcanbeanalyzedasfollows: WhenPVsystem,FuelcellsareintegratedintoACsystemsthereisaneedforDC/ACconverter soastosupplythepowerintoACsystem. Other thanthatDCpower canalsobedirectlyutilizedforDCoperatingsystems. WhenACpowerisgenerateditneednotbeconvertedinordertobesuppliedtotheACload.Thism inimizestheconversioncostandmakesthesystemeasytouse.WhenDCloadsareconnectedtos uchsystemrectifiersareusedsuchasDC-AC-DC-ACalongwithDC/ACinverters.

InDCsystems,no DCconversionisrequired for DCloadsandthepower consumed bythesystemisDC.IfDCsourcesareconsumedbyACsystem,thenconversionfromDC-ACorAC /DCis requiredas perspecificationofthesystem. ModeofoperationofHybridmicrogrid: Theoperatingmodesofhybridmicrogridarebasedonthetypeoftopologyusedandflowofpow erinthesystem. / Figure3.4 OperationofACMicrogrids[12]

/ Figure3.5 OperationofDCMicrogrids[12] /
Figure3.6OperationofHybridMicrogrid:DCtoAC flow[12]

/ Figure3.7

OperationofHybridMicrogrid:ACtoDCflow[12]
Asseeninfigure(a)and(b)thesystemisworkingaspureACandpureDCmicrogridrespectively.In figure(c)&(d) showsinterfacingbetweenAC andDCsystems.
Infigure(a)onlytheACsourcesareworkingandsupplyingpowertoACload.Thereisnoconnecti onwiththeDCmicrogridanditsinterconnectingbusbars.Alsowhenneededitcansharepowert otheexternalACgrid.InFigure(b)only
theDCsourcesareworkingtosupplypowertoDCload.Ithasnoconnectionwith ACmicrogridan ditsinterconnectingbusbars.Similarly,itsharespowertotheexternalDCgrid.InFigure(c)depict thattheDCsourcesareinconnectionwiththeinterfacingbusbarstosupplyACloadandalsoshar epowertothegrid.Thisconceptshowsatypeofhybridtechnology.Figure(d)isfortheACsourcei sconnectedtotheinterconnectingbusbarstosupplyDCloadusingAC/DC
converter.AlsoitsharespowertotheDCgridasandwhenrequired.

Chapter4DESIGNOFMICROGRID GeneralStructureofMicrogrid
ThisislandedmicrogridiscomposedoftheDG,thedistributionnetwork,thecontrolsystemandtheload.Morespecifically,thedistributedgeneratorsarecomposedofthePhotovoltaic(PV)systemandthewindturbinesystemsothismicrogridusesrenewableenergyastheresource.BoththePVsystemandthewindpowersystemhavetheirowncontrolsystem.Thegeneralstructureofthemicrogridis shownintheFigurebelow: Figure4.1Structureofthe Microgrid / Figure4.1showsthebasicstructureofthemicrogrid,whichincludes the Distributiongrid,thewindturbineequippedwiththepitchcontrollerandtheMPPTcontroller,thePhotovoltaic,theenergystoragesystem,thebattery,thedistributionlinesandtheload.Thedistributedgeneratorsusewindandsolarasresources.TheESSwhichincludestheconverterandthebatteryisusedtosupplyor
assimilatepower.IntermsofthecontrolofthewindpowersystemthepitchcontrollerandtheMPPTcontrolareincluded.Finally,thedistributionlines
andtheloadarealsoaddedastheindispensablecomponentsofthemicrogrid.

IntermsofthePVsystem,eachsolarpaneliscomprisedofanumberofsolarcellsthat

generateelectricpower[33].PVpanelconverseslightintoelectricityanditproducesnopollution;thistechnologyhasbeenusedsincehalfacenturyagoand isgettingcheaper andmoreefficientnowadays.ThePVsystemalsoincludestheconverterthatconnectsthepanels andtheinverter.Furthermore,anenergystoragesystemisalsobuilttoprovidepowertotheload whenthereisnosunlightandtheirradiancebecomes0. Windturbineconvertskineticenergyofthewindintoelectricpoweranditcanbemanufacturedi nbothverticalandhorizontalaxistypes[33].Thesmallandmediumsizedwindturbinesareusedf orapplicationssuchasbatterychargingforauxiliarypowerforboatsorsupplyingdomesticpow erwhilesellingunusedpowerbacktotheutilitysupplierviatheelectricalgrid[34].Arraysoflarget urbines,knownaswindfarms,areusedas themainsourceofrenewableenergyandareusedbymanycountriesasthereplacementoffossilf uelsandoil[35].

Sincemostofthewindplantsinthemicrogridarecomposedofvariable-speedandhorizontalaxi swindturbines,thisthesisalsochoosethesametype(variable-speedandhorizontalaxis)as thewindturbine. Theblockdiagramofmicrogridindetailsisshowninfigure4.2asbelow: / Figure4.2 BlockDiagramofthe Microgrid inDetails Thisisthearchitectureofthemicrogridsystemanditincludestwodistributedgenerators(PVand windturbine).Thebatteryenergystoragesystem(BESS)ofPVsystemandtheMPPTofwindpowe rsystemcancommunicatewitheachothersothemicrogridcan becontrolledcoordinately.Thismicrogridsystemcanbeconnectedor

disconnectedtothedistributiongrid.Whenthedistributiongridhasbeendisconnected,themicrogridcanprovidepowertothelocalload.

SpecificDesignofthePVSystem

ThefirststepistodesignthePVsystem.Theblockdiagramstructure ofthePVsystem isshowninFigure4.3as below: / Figure4.3StructureofthePVSystem

Theoutputofthesolarpanelisdictatedbythesolarirradianceandtheenvironmentaltemperature.Inthiscase,weassumethetemperatureis15degreesCelsius.TheoutputsolarpanelthedcpowerintotheboostconvertersoboostconvertercanregulateoutputsolarpanelbasedontheMPPTcontroller.ThentheDCpowerissenttotheinvertersystem,whichiscontrolledbythedroopcontrolsystemsotheACpowerisdeliveredtothemicrogridbus.Thebatteryenergysystemcan becharged ordischargedaccordingtothesolarpaneloutput.

FromFigure4.3,itisclearlyseenthatthePVsystemiscomposedofthePVpanel,thecontrolsystem,theMPPTandtheEnergyStorageSystem(ESS).InMPPT,ittracksthemaximumpoweroutput ofthesolarpanel;droopcontrollerdecides theoutputpowerofoverallPVsystem,andBESScanbecharged/dischargedbasedontheoutput powerofthesolarpanel.WhenthePVpanelcannot output

TheequivalentcircuitofthePVcellisbasedonthemodelasshowninFigure4.4asbelow:

/ Figure4.4EquivalentCircuitofthePVArray

Asthefigureshowsabove,Iphisthephotocurrent,IDisthecurrentofthediode,Rshistheshuntresistanceand Rsistheseriesresistance,andIshrepresentstheshuntcurrent.Basedonthephotoelectriceffect,theequationofIphcan berepresentedasbelow[36]: /(4.1)

WhereSrepresentsthesolarradiation,Iscistheshort-circuitcurrentatthestandardtemperature.Ktrepresents the

shortcircuitcurrenttemperaturecoefficientofthecell.Trefisthereferencetemperatureand/Ihasthevalueof1000W/m2.Basedonthecharacteristicsofdiode,theequationoftheIDcanberepresentedas(2.2)andtherelationofthevoltageandcurrent ofp-njunctioncanberepresentedas equation4.3: /(4.2) /(4.3)

Whereqhasthevalueof1.6e-19CandK=1.38e-23.IOisthereversesaturationcurrent.Basedonequations2.1,2.2and2.3,thecharacteristicequationforthevoltage-currentofasolarcellisgivenas [36]:

(4.4) Inorderincreasethecapacityoftheoutput powerofthePVarray,multiplephotovoltaiccellsareinterconnectedinparallelandseriestohave desiredvolt-amperecharacteristicsoftheentirephotovoltaiccellarray.Therevisedequationis givenas[31]: /(4.5) WhereNpisthe number ofPVcells thatareconnectedinparallel;NsisthenumberofPVcellsinseries.Also,thecell'ssaturationcurre ntvarieswiththetemperatureof thecell as describedintheequationshown below[36]:

/ WhereECistheband-gapenergyofthesemiconductorin thePVcell. _ (4.6)

Theboostconverterisdesignedasastep-upconverterthataimstoincreasethevoltagetoahighe routputvalue.Inthis case,theoutputsolarpaneltheDC powerintotheboostconverter,so theboostconvertercanregulateoutputsolarpanelbasedonMPPTcontroller.

Battery EnergyStorageSystem Itis verychallengingtocontrolandoperatetherenewablemicro gridduetothevariabilityandintermittencyofdistributedgeneratorsthatuserenewable energy.
Therefore,anenergystoragesystem(ESS)isnecessaryinthePVsystem.TheESScanprovidethes pecificvoltageandfrequencysupportfortheislandedmicrogridanditchangesthepoweroutpu ttoregulatethefrequencyandvoltagetothescheduledvalues[37].Therefore,theEnergyStorag eSystemplaysavitalruleinstabilizingthemicro grid.TherearevarioustypesofconvertersintheEnergyStorageSystem,suchasDC-DC

andDC-ACconverters.Sincesolar paneloutputsDCpower, aDC-DCconverteris usedinthiscaseinordertochangethevoltagelevel.Thebuck-boostconverterisindispensableb ecauseitisabletobothchargeanddischargetheBatteryEnergyStorageSystem(BESS),therefor echangingthedirectionofthepowerflowaccordingtodifferentsituations.Forinstance,thevolt ageoftheenergystoragesystemwillbesteppedupwhenitsvoltageislowerthanthatofthemicro gridsidesothatthebatteryenergystoragesystemcandischargetosupplypower tothemicrogridandviceversa[38].

Inthisthesis,thebatteryenergystoragesystemconsistsofonebuck-boostbidirectionalconvert erand onebattery; thestructureoftheconverterisshowninFigureas below: / Figure4.5 StructureoftheBuck-Boost BidirectionalConverter
Powerallocationisachievedbycontrollingthedirectionandvalueoftheelectricalpowerflowing throughthebi-directionaldc/dcconverter.C1isthelow-voltagesideandC2isthehigh-voltageside.
Asitisshownabove,theinductanceis2.332mHandthediodehastheresistanceof 0.001ohm,forwardvoltageof0.3V.BoththeMOSFETandinternaldiodehavetheresistanceof1o hm.Basically,whenMOSFET1(S1)isswitching,andMOSFET2(S2)iskeptonanditistheboostcon verter;thebatterydischargestheenergytothemicrogrid.WhenS1isOFF,S2is switching,itisthebuckconverterandthebattery isgettingcharged[39].
TheothercomponentofthebatteryenergystoragesystemisthebatteryThebatterytypeistheLi thium-ioninthiscase.Oneofthereasonstochoosethistypeofbatteryisthat Lithium-ionbatteryi saverypopulartypeofrechargeablebatterywithahighenergydensity,tinymemoryeffectandlo wself-discharge[40].Thenominalvoltageis

set to be 311voltsandtheratedcapacityisset tobe 1000 Ahwiththemaximumcapacityof1077 Ah.Therefore,thebatteryhasanappropriatecapacitythatisneithertoolarge nortoosmall based onthesevalues.
TheoutputoftheboostconvertergoestotheVSC,voltagesourceconverterandthecircuitisshownin Figure4.6as below: / Figure4.6CircuitoftheVoltageSourceConverter Asthe figureshows, therearesixswitches (S1toS6)pairedwithsixdiodesin thethree-phasevoltageinverter.Udcisthedirectoutputvoltagefromthesolarpanel,Cdcisthefilter capacitor,Lfisthefilterinductor andRfisthefilter resistance.ua, ub,ucrepresenttheoutputvoltagesoftheinverterandia,ib,icrepresenttheoutputcurrentsoftheinverter.

ControlSystemofPV
ThecontrolsystemofPVisalsosignificant.Thecontrolsystemisexpectedtocontrolthefrequency,theoutputpowerandthevoltageinthePVsystem.ThestructuresofthePVcontrolsystemareshownin Figure4.7: / Figure4.7StructureofthePVControlSystem

Asitisshownabove,thePVcontrolsystemcalculatesthepoweroutputoftheVSCusingfeedback signalsVabcandIabc,thendroopcontrollercangeneratereferencesignalsothevoltageandfre quencyofmicrogridcanberegulated.Thenthereferencesignalsaresent tothedual-loopPIcontrollerinwhichtheouterloopisvoltagePIcontrollerandtheinnerloopisth ecurrentPIcontroller.Thedual-loopPIcontrollerhasthestructuresasshownbelow: / Figure4.8StructureoftheVoltageController / Figure4.9StructureoftheCurrentController Thereiscouplingeffectwhenconvertingthethree-phasevoltageandcurrentoftheVSCintothe voltageand
currentofd-axisandq-axis,sothedecouplingterms(wCfvoq,wCfvod,wLfiiq,wLfiid)areaddedi nthevoltageandcurrentcontroller[41].

WindPowerSystem
Theseconddistributedrenewablesourceisthewindenergyconversionsystem(WECS).Variabl e-speedWindTurbineGenerator(WTG)iscontrolledbythepowerconverterthatisinterfacedbe tweentheWTGandgrid.Therearetwotypesof

variable-speedWTGs,doublyfedinductiongenerator(DFIG)andpermanentmagneticsynchronousgenerator(PMSG).Incomparisonwithadoublyfedinductiongenerator,aPMSG-WTGhashigherefficiencyandreliabilitybecauseitcan bedrivendirectlybyawindturbinesincetherotatingspeedofthegeneratorissloweddownwiththemulti-polestructure.Ontheotherhand,thePMSGisalsoexpensiveforitshighcostofconverter[42].Sincethis thesisfocusesonthesmall-sizedgrid,thePMSGis usedhereasthetypeofwindturbinegenerator.ThetypicalstructureofthePMSGisshowninfigure4.10as below: Figure4.10StructureofPMSG InPMSG,theairgapfluxismaintainedbythepermanentmagnetandonlytheq-axiscurrentdecidestheelectricaltorquebecausethereisthed-axiscurrentcontrolledtobe0bythegenerator-sideconverter(GSC)[42].Inthisthesis,thewindpowersystemiscomposedofthewindturbineandsinglemassshaft,theWindPowerPlant(WPP)Integration,theMPPTcontrollerandthepitchcontroller.

4.5.1Wind Aerodynamic andSingleMassShaft Thewindaerodynamicandsinglemassshafthasthestructureasshownbelow: / Figure4.11StructureoftheWindAerodynamicandSingleMassShaft AsitisshowninFigure4.11,therearetwoconversionprocessesinthewindturbinegenerator.Thewindturbinegetsthetorquefromthepressureofthewindandthe

mechanicaltorque isconvertedintoelectricpowerthroughthegenerator[42].Thesinglemass shaftis based ontheequationbelow: /(4.7)
Thedifferencebetweenthewindturbinetorqueandthegenerator torqueisinproportionaltot::w.Hhasthevalueof3andthenusingtheequationofrotorspeedt::w +wO=w,wherewO=O.5andisaddedtothespeedtocalculatetherotorspeed,whichissenttothe windturbine. Thewindaerodynamicfunctionisbased onequation4.8asshownbelow: /(4.8)
Thepowerofthewindturbineisinproportionaltotheairdensity(p),theareaoftheturbineblade(r rR2),thewindspeed(v)andthepowercoefficientoftheblade(Cp(/l,8)).Theairdensityis1.225kg/ m3andradiusofthebladeis39.26m.Thepower coefficientisalsorelatedtothetipspeedratio(TSR)/l andthepitchangle8;where/l CR =.Therefore,itisnecessarytoadjustthe turbinespeedaccordingtothewindspeed v Inordertogetthemaximumpowerandconversionefficiency.

AccordingtotheBetzlimit,thepowercoefficientofthebladehasatheoreticalmaximumvalueof 0.59.Then thevalueofthepowercoefficientoftheblade((/l, 8))isfigured outbythevalue of/land thevalueofthe pitchangle8.
Thebasicstructureofthepitchcontrollerisshownasbelow: / Figure4.12StructureofPitchController AsitisshownfromtheFigure3.3,thepitchcontrolleris capableofrestrictingtherotorspeedunderhighwindspeedbyturningthebladeangleofattacka nditisclampedto

theoptimalvalue,whichissettobe0degreeswhenthewindspeedisbelowtheratedvalue[43].Whenthewindspeedexceedsthespeedoftheratedvalue,thepitchcontrollerincreasestheangleoftheattackoftheblade,thereforemakingthereductionintheliftforce;whenthebladeisfullypitched,thepitchcontrollermakesthebladeangleofattackalignedwiththewindsothattheliftforceis zero
inthisoccasion,thusreducingtheloadsontheturbinemechanicalcomponentsandavoidingarun-awaycondition[44].Thepitchanglesaturationandthe rate
limiterarealsoaddedintothepitchcontroller,in
whichthepitchanglerangesfrom0to30degreesandthepitch
ratelimitissettobe10degree/second.Thereforeitpreventsthebladesfromdamagingduetofrequentlyoperatingtheblades.

EnergyStorage System
EnergystorageSystem(EMS)isusedtohelpthedistributionsystemsatpeakloadastheconsumption of
electricityishighbythecustomers.Thusenergystorageunitsareusedinordertosupplytherequiredbalancedpowerbetweentheloadandgenerationunits.Therebyprovidingenergytothegridandothermicrounitshavinginsufficientenergytomanagetheload.Thisproblemarisesasthedemandincreasesincertainareaandthatexcessrequirementisdifficulttomeetbythedistributed
resources
presentinthatarea.Inordertomeettheseadditionalrequirements,theEnergystoragesystemcanbeusedtoboostthesystemrequirementingivenperiodoftimeandavoidpoweroutage.
Energystoragesystemstorestheexcesspowergeneratedduringoff-peaktimeandduringpeakdemand,whenthereisheavyutilizationofpower,thestoredenergyinEMSisusedtofeedthedemand.Varioustechnologiesisimplementedtostorethisenergyinbatterysystembutmostcommonlyflywheelsandelectrochemicalcapacitor.Fewothertechnologiesusedinthissectorarecompressedairenergystorage(CAES)andsuperconductingmagneticenergystoragesystem(SMES). FuelCell: Fuelcellmakesuseof
chemicalreactiontogenerateelectricity.ItispossibletogenerateelectricitywithminimumpollutionbymakinguseofFuelcell asitmakesuseofhydrogenandoxygento
ultimatelygenerateelectricityandaharmless byproduct,water.Fuelcells
provideefficientandcleanenergyusingthis energyconversion
andthusregardedasrenewableenergyresources.Ingeneral,chemical
reactiontakesplaceinsidethefuelcellanditmakes useoftwoelectrodes,ananodeand
cathoderespectivelyandan

electrolytebetweenthemforthereactiontotakeplace.Hydrogenisthebasicfuelforthereaction totakeplacebut italso makesuseofoxygenandacatalysttospeedupthereaction[45].

Asfuelcells arestaticinnaturebecauseoftheirquietoperationwithoutnoiseorvibrationanditssimplemodular construction makesthemhighlyefficient.Thusfuelcellprovidesacleaner,muchefficientandflexiblesourceof energy.Afuelcellconsistsoffollowingcomponents: Anode,cathodeandanelectrolytebetweenthem.Thefigurebelowshowstheprocessoffuelcell operation: / Figure4.13Fuelcelloperations[46] Thechemicalreactiononwhichthisoccursisasfollows: H2=2H++2e- Thehydrogenionstravelthroughtheacidicelectrolyteandthe electrons traveltothecathodeendtocompletethecircuit.Atcathodeend,theelectronsandhydrogenion sreactwithoxygenwhichis supplied to thetankthroughexternalpipelinetoformwater.

O2+2H++2e- =H2O Thetotalreactionoffuelcellisshown belowwhichgivesoutwater,electric work andheatas output: H2O+O2=H2O+Wele+Qheat

Theby-products;heatand waterarecontinuouslyremoved soastocontinuouslymaintaintheisothermaloperationforgenerationofelectricity.Therefore, waterandheatneedstobemanagedefficientlyforeffectiveoperationof fuelcells.

ComparisonofFuelcellandBatterywithIC engine: Thefuelcellandheat enginesmakeuseofhydrogenbasedfluidasfuelandairasoxidants.Butthefuelcellelectrochemically convertsthefuelandoxidantswhereasICengineusescombustionprocessforthesame.As combustionisamultistepprocessitfirstly,producesthermalenergyfromchemicalenergyofthe fuelandthenisconvertedtomechanicalenergyandeventuallygeneratorsareusedtoconvertiti ntoelectricalenergy.

/ Figure4.14 ComparisonofFuelcell, BatteryandICengine

Fuelcellandbatteriesworkonsameworkingprincipleandconsistofelectrochemicalcells i.e.electrolytebetweentwoelectrodes.Inorder togenerateelectricalenergy,bothsystemuseoxidationreductionmethodstoconvertthestore dchemicalenergy.Butthetypeofmaterialanditscompositionsignificantlydiffersforboth ofthem.Inabatterymetalrodsareimmersedinacidicsolutions.Thefuelcellconsistsof2electrod esandanelectrolyteforconductionandtransportationofelectrons.Inabattery,theenergystore din electrodesisutilizedbyelectrochemicalreactionsatcertainpotentialdifference.Thus,abattery haslimitedlife timeandcanbe usedtill completedepletionofelectrode materialdoesn'ttakeplace.

CHAPTER5RESULTSANDDISCUSSIONS Overview

Theproposedhybridenergysystem,showninFig.1&2consistsofDFIGbasedvariablespeedwindenergyconversion,PVarray,battery,fuelcellandelectrolyzer.WTandPVenergysourcesaremanagedwithmaximumpowerpointtracking(MPPT)algorithmsandconnectedtothecommonDCbus.Where,intheWTcase,

theMPPTalgorithmisappliedatbelownominalturbinespeed.Beyondthenominalspeed,wewillbeacting

onthepitchanglecontrol,whereasthepowerextractionmaximizationamountstoregulatethepowerproducedatitsratevalue.The

Batteryisusedasastoragedeviceandisconnectedtothe DCbusthroughDC/DCBuck-Boostbidirectionalconverter(BBDC).Windandsolarpowerdependonweatherconditionsandduringnighthourssolarpoweriszero.Therefore,underthesituationoflongtermno-windandsolarorlow-windandsolarcondition,batteryalonecannotcatertheloaddemand.Hence,fuelcell(FC)isintegratedtomakethesystemmoresustainable.Incaseofhighpowergenerationfromwindandsolarforalongtimeandthebatteryreacheditsupperlimitof

chargestorage,theelectrolyzercomesintoeffectandconsumesthesurpluspower.Thehydrogengeneratedfromtheelectrolyzercanbestored and usedasinputbyFC.

/ Fig 5.1HybridPV/WTandFCsystemwithtransmissionlineandload ElementsofSystem
Typically,grid-connectedPVsystemconsistsofsolarpanels,DC-DCconverter,MPPTcontroller, inverterandgridconnectionequipment.Ithasnoenergystoragelossessincethereare nobatteriesusedasitisnotastandalonesystem.Thesystem'scomponentsaremodeled in Matlab/Simulink softwareenvironment.Matlab/Simulink isselected,duetoitsreusability,extendibility,andflexibilityinsuchsystems.Itisadynamicmodel wherethesimulationtimeis3s,samplingtimeis10-5s,sincethetimestephas tobelowerthanthepropagationtime.Themodelcanpredicttheperformanceofthesystemand assessitbycomparingthesetuptonewintroducedsetupswithaddedcomponents,solvingaset ofnon-linearequations.AschematicoftheSimulinkmodelisshowninFig.5.1.

Photovoltaicarray
Solarcellsexhibitnon-linearcurrent-voltagecharacteristicsasshownbelowthatdependonsolarradiation andtemperature. /(5.1)
WhereIphisthephotocurrent,Ioisthesaturationcurrentofthediode,Rsistheseriesresistance,Rshistheshuntresistance,nisthediodeidealityfactor,kisBoltzmann'sconstant(1.4x10-23),qistheelectroncharge(1.6x10-19),TistheabsolutetemperatureinKelvin. Inveter
Allphotovoltaicsystemsinterfacetheutilitygridthroughaboostconverterandavoltagesourceinverter.TheDC-DCconvertersareusedtobalancethesystem.Invertersareresponsibleforconverting DCpowertoACpower.ThisisdonebyswitchingtheDCinputvoltage(or current)inapre-determinedsequencesoastogenerate ACvoltage(or current)output.Three-phaseinvertersconsistofone,two,orthreearmsofpowerswitchingdevices.Eacharmconsistsoffourswitchingdevicesalongwiththeirantiparalleldiodesandtwoneutralclampingdiodes.ThecontrolsignalgeneratedbyanyMPPTmethod,feedtheboostconverter switch.

MPPTcontrol There isapointwheretheoutputpower fromthearray(astringofpanels)hasamaximumvalue.Inordertoensureefficientoperationofthesolararraytheoperatingpointofthearrayhastobetracked.MPPT,inadditiontoraisingthepowerdeliveredfromthePVmoduletotheload,isconsideredasaPVsystemlifetimebooster.Thereare manycontrolstrategiesandcontrollertypes.Thesemethodscanbegroupedbasedondifferent features.Inessence,MPPTmethodsarecategorizedinto:offlinemethodswhicharedependent onsolarcellmodels,onlinemethods whichareusuallyreferredtoasthemodel-freemethod.

TheMPPTtechniquethatgeneratesthecontrolsignalwhichfeedstheboostconverterisassumedtobefractionalOCVtechnique.ThistechniqueisundertheMPPTofflinemethodswhich generallyrequiretheknowledgeofoneormoreofthesolarpanelparametersvalues;heretheopencircuitvoltage(VOC).Thesevaluesgeneratethecontrolsignalnecessaryfordriving thesolar celltoitsMPP.Inthetrackingoperation,thiscontrolsignalremainsconstantifambientconditionscanberegardedasfixedandtherearenoattempts toregulatetheoutputpowerofthePVsystem.

TheOCVtechniqueischosenbecauseitisoneofthemoststraightforwardofflinemethods.Itusesthealmostlinearrelationshipbetweentheopencircuitvoltage(VOC)andtheMPPvoltage(VMPP)underchangedclimaticcircumstancesasdescribedbythefollowingequation: VMPP=k*VOC Wherekisaconstant,dependingonthesolarcellcharacteristics. Theconstantkisderivedempiricallyafter measuringseveralVOCandVMPPforanyspecificcellunderdifferentclimaticconditions.Values fortheconstantk,ingeneral,varybetween 0.73to0.80,hereinourspecificcase, theconstantkisassumedtobe0.8. TheefficiencywascalculatedofthetechniquebythefollowingformulashowninEq.(5.2),tovalidateit: /(5.2) Whereriistheefficiencyofthetrackingmethod,Pmax.trackedistheMPPtrackedand Pmax.istheactualMPPofthearrayderivedbythefollowingequation:Pmax=VMPP*No.ofseries modules*IMPP*No.ofparallel WhereVMPPisthevoltageofthesolarcellatMPPandIMPPisthecurrentofthesolarcellatMPP,bearinginmindthatthesetwoparametersvaryaccordingto radiationandtemperature.

5.2.4Transformer

ToconnectthePVsystemtothenationalhighvoltagegrid,atransformerisaddedtothesystem.Itsfunctionistochangetheratioofvoltagetocurrentdeliveredfromavoltagesourcetomeetthecharacteristicsoftheload,keepingthepowerconstant.Transformersconsistofprimarycoilwhichreceivesenergyfromthe ACsource(heretheinverter),secondarycoilwhichreceivesenergyfromtheprimarywindinganddeliversittotheload(herethenationalgrid)andthe corewhichmakesa pathforthemagneticflux. / Fig5.2BasicDiagramofTransformer

Transformersareeitherstep-up(deliverhighervoltagetotheload)orstepdown(deliverlowervoltagetotheload)according totheratio ofthenumberofturnsofthesecondarytotheprimary.

/(5.3)

Where:V1,I1arethevoltageandcurrentreceivedfromthesourcetotheprimarycoil;V2,I2arethevoltageandcurrentdeliveredtotheloadfromthesecondarycoil;n1,n2arethenumberofturnsoftheprimaryandsecondarycoils.Asforthe highvoltageassumedgrid,itconsistsofadistributionfeederandatransmissionsystem.

Modelformulationand structure A.PhotovoltaicCell

ThePVcellmathematicalmodelisrepresentedhere.ThetypicalPVmodulepowercharacteristicisgiveninFig1.Inordertoextractthemaximumavailablepowerfroma

PVarray,itisnecessarytooperatethePVarrayatitsmaximumpowerpoint.TheMPPTdevice isahigh-frequencyboostdc-dcconverterinsertedbetweenthePVarrayandthedcbus,andittak esthedcinputfromthePVarray,convertittoadifferentdcvoltageandcurrenttoexactlymatchth ePVarraytothedcbus.

/ Fig5.3 PV/WTand FCtoDC-DC bus andDC-ACBus

/ Fig5.4 Modeling ofPVwith irradianceandtemperature
Fig.5.4showsthattheoutputpowerisdirectlyproportionaltotheirradiance.Assuch,asmallerirradiancewillresultin reducedpower outputfromthePVmodule.However,itisalsoobservedthatonlytheoutputcurrentisaffectedbytheirradiance.Thisisexpected,becausethegeneratedcurrentisproportionaltothefluxofphotons.AccordingtoVmpptheyresult4arrays areconnectedin parallel;eacharrayconsists of27modulesconnectedin series.Eachofthemdelivers 108Wpeaks. / Fig5.5 CalculationofPhotoCurrentinPVmodel

/ Fig5.6CalculationofShortcircuitCurrentinPVmodel /
Fig5.7TypicalPVmoduleunitI-VandP-Vcharacteristicshowingtheeffectsofirradiance
WindEnergyConversion
Theaerodynamicpowerattherotoroftheturbineisgivenbythefollowingequation: (5.4)

Wherepistheairdensityinkilogrampercubicmeter,Aistheareasweptbytherotorbladesinsquaremeter,andvisthewindvelocityinmeterspersecond.Cpiscalledthepowercoefficientortherotorefficiencyandisafunctionoftipspeedratio(A)andpitchangle(?).

/ Fig5.8 Modeling ofWTwithconverters FuelCell

TheFCisadevicefordirectlyconvertingthechemicalenergyofafuel,intoelectricalenergy.Theoutputvoltageofasinglecellgivenin[10-12]canbedefinedasin(5.5): /(5.5)

WhereENernstisthereversiblevoltage,EActistheactivationvoltagedrop,EConistheconcentrationvoltagedrop,andEOhmistheOhmicvoltagedrop. Theterminal voltageofPEMfuelcellstacksisdefinedasin(5.6). (5.6)

/ Fig5.9Modeling ofFCwithconverters
Fig.5.9showsvoltageandpowerversuscurrentpolarizationcurvesofaPEMFC.Itisshownthatth eactivationvoltagedropdominatesatlowcurrent,theOhmicdropvoltagedominatesatmid-ra ngecurrent,andtheconcentrationdropvoltagedominatesathighcurrent.Thevoltagedeviates furtherasthecurrentisincreased,illustratingtheeffectsofdropvoltages.Inconcentrationvolta gedropregion,theFCoutputpoweroccursneartheFC ratedpower. /
Fig5.10PowerandvoltageversuscurrentpolarizationcurvesofPEMFC
TheFCcontrollerthroughwhichtheboostconverterswitchiscontrolled.Controllersassociated withthebatteryandFCaredevelopedinsuchafashionthatwhenthereisa

suddenrequiredpowerchange,thebatteryprovidesthepowerinstantaneouslyandasFCpowergoesonincreasing,batterypowershouldgoondecreasing.Inordertomakethepropercoordinationbetweenbatteryand FC,boostconvertercontrollerassociatedwithfuelcellisdevelopedbasedonandassumingbatterycurrentisideallyzero.Moreover,whenthebatterystate ofcharge(SOC)isbelow20%,thefuelcellshouldgivepowertothebattery.ThePEMfuelcelliscomposedof2x6stackswiththepowerrating of10kW. / Fig 5.11TypicalU-I characteristicofanelectrolyzerunderdifferentTemperatures Electrolyzer Thedescriptionof thewaterelectrolyzerisdevelopedhere.TheU-Icharacteristicsof theelectrolyzermodelusedin thisstudyatdifferentcelltemperatures.Atagivencurrent, thehighertheoperatingtemperature,theloweristheterminalvoltageneeded.TheexcessenergyproducedisfirstpushedintothebatteryuntilitreachesitsupperlimitofchargecarryingcapacityandthentheexcesspowerisfedtotheelectrolyzerandisregulatedviathebuckDC/DCconverter.Thedecisionaboutswitchingonthecontrolactioniscarriedoutbycomparingtheupper limit ofthestateofcharge(SOC)ofthebatteryandthepresentstatusofSOC.WhentheSOCbecomeshigherthanitslimit,80%,thecontrollerwillincreasethedutycycleas afunctionofovervoltageinthedc busvoltage. SIMULATIONRESULTANDDISCUSSION Usingthecomponentmodels,asimulationsystemtest fortheproposedWTDFIGs/PV/FC-ElectrolyzerenergysystemhasbeendevelopedusingMATLAB/Simulink,theWT-DFIGsandthePVparametersaregiven.Inorder toverify

thesystemperformanceunderdifferent
situations,simulationstudieshavebeencarriedoutusingvariableloaddemanddataandrando
mweatherdata(windspeed,solarirradiance,andairtemperature).

/ Fig5.12 DC-DC Microgridvoltage / Fig5.13SOC, Currentand VoltageofBattery

/ Fig5.14CharacteristicofFC / Fig5.15VoltageandCurrentofFC

/ Fig5.16VoltageandCurrentofDC-ACConverter

/ Fig5.17VoltageandCurrentofLoad

CHAPTER6CONCLUSIONANDFUTURESCOPE CONCLUSION

Thisdissertationisonmodelingandcontrolofahybridwind/PV/FCalternativeenergysystem.Themainpartofthedissertationfocusesonthemodelingofdifferentenergysystemsandthecorrespondingcontrolschemedevelopment.

DGsystemmodelingandcontrolaretwootheraspectsoftheresearchpresentedinthedissertation.AhybridalternativeenergysystemhasgreatpotentialforuseasaDGsource.

Theconclusionsoftheresearchworkreportedinthisdissertationaresummarizedasbelow.

Environmentallyfriendlyandsustainablealternativeenergysystemswillplaymoreimportantroles in thefutureelectricitysupply.

Dynamicmodelshavebeendevelopedforthefollowing:fuelcells(PEMFCsandSOFCs),variable speedwindenergyconversionsystems,photovoltaicpowergenerationsystems,electrolyzers, powerelectronicinterfacingdevices,batterybanksandaccessoriesincludinggascompressor, high-pressurehydrogenstoragetank,andgaspressureregulator.Thesedynamicmodelsaresuitableforbothdetailedfasttransientandlargetimescaleperformanceevaluationstudies.Theycanbeusedtoexpediteresearchprocessesinrelatedalternativeenergyareas,suchas systemcontrolandperformanceoptimizationstudies.

Ahybridwind/PV/FCDGsystemisproposedinthisdissertation.WindandPVaretheprimarypowersourcesofthesystem,andthecombinationofFCandelectrolyzerisusedasabackupandlongtermstorageunit.Thedifferentenergysourcesinthesystemareintegratedthroughan AClinkbus.Thesystemcanbeusedastest-bedsystemforotherrelatedstudiesonhybridalternativeenergy systems.

Basedonthedynamiccomponentmodels,asimulationmodelfortheproposedhybridwind/PV/FCenergysystemhasbeendevelopedsuccessfullyusing

MATLAB/Simulink.Theoverallpowermanagementstrategyforcoordinating thepowerflowsamongthedifferentenergysourcesispresentedinthedissertation.Simulations tudieshavebeencarriedouttoverifythesystemperformanceunderdifferentscenariosusingpr actical loadprofile. FutureScope
Thenextstepinresearchistoconsider Microgridasasystem.Itisessentialtoknowmoreabouth owthesourcesinteractwitheachother.More
specificallytheirrelationshiptoeachotherneedstobedefined.Ifallgoesasanticipatedandthe Microgridsystemisdeveloped,thecontrolofthesystemwilllikelybeimbeddedwithintheelectr onics.Itispossibletousespecializedcontrollerstogetamorestableresponseandtouseeachpo wersourcemoreefficiently.Thisshouldcertainlyberesearchedandconsideredoncethepowers ourcesinteractionandrelationshipwitheachotherandthemainshavebeendefined.Otheraspe ctsthatcouldbedevelopedfurtheraretheindividualsourceswithintheMicrogrid.Thiscouldbe doneattwolevels.Thefirstis theconsideration ofother variablesforeachsourc

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